Climate Data Management System

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CHAPTER 1

Introduction

1.1 Overview

The Climate Data Management System is an object-oriented data management system, specialized for organizing multidimensional, gridded data used in climate analysis and simulation.

1.2 Basic Concepts

The building blocks of CDMS are variables, container classes, structural classes, and links. All gridded data stored in CDMS is associated with variables. The container objects group variables and structural objects. Variables are defined in terms of structural objects.

Most CDMS objects can have *attributes*, which are scalar or one-dimensional metadata items. Attributes which are stored in the database, that is are persistent, are called *external* attributes. Some attributes are *internal*: they are associated with an object but do not appear explicitly in the database.

1.2.1 Variables

Most of the data stored in CDMS has the form of multidimensional data arrays. A *variable* is a persistent, multidimensional array, together with associated metadata. A persistent variable retains its value independent of an application.

A variable may be viewed as a function which maps a multidimensional *domain* onto a range of values. The domain of a variable consists of an ordered tuple of axes and/or grids which define the shape and spatial orientation of the variable.

1.2.2 Container classes: Databases, Datasets, and CdmsFiles

Variables are contained in *datasets*. A *dataset* is a collection of variables and associated structural objects. All objects in a dataset are identified by a string ID, unique within the dataset.

The data contained in a dataset generally is stored in one or more physical datafiles. An additional ASCII metafile describes how the files are organized and named. In a climate simulation application, a dataset usually represents the data generated by one run of a general circulation or coupled ocean-atmosphere model.

The metafile associated with a dataset can contain information which is additional to that in the actual data files. The format of the metafile is designed for readability, ease of extension, and integration with Web browsers. It can be used to enforce naming standards, by ‘aliasing’ variable names. The format of the metafile is based on the World Wide Web Council standard XML language.

A *Database* is a collection of datasets and other CDMS objects. A Database:

- provides naming mechanisms for accessing and searching its contents independent of local file names.

- may be associated with a server, local or remote. A given site would ordinarily have only a small number of Databases, perhaps one public and a few private ones.
- provides a facility for standardization of data. The objects contained in the Database can be required to adhere to a metadata standard such as GDT. This provides assurance that data access will be robust.

The process of copying external data into a Database is known as the *ingest* process. Ingesting data into CDMS involves verifying that data adheres to a standard. Mechanisms are provided for adding metadata to meet that standard. The *cdimport* utility is used to ingest data into CDMS.

CDMS permits access to data files which are 'outside' a database. In CDMS, a file is termed a *CdmsFile*. CdmsFiles are similar to datasets, in that they are containers for variables, axes, and grids. However, not all CDMS objects can be stored in CdmsFiles. Also, the standardization associated with the ingest process may not apply to a CdmsFile. Data may be read from a variety of self-describing file formats, including netCDF, HDF, GRIB, and PCMDI DRS formats.

1.2.3 Structural classes: Axes and Grids

Structural objects are used in the definition of variables. They define how a variable is oriented in space and time. For example, suppose that a variable is a function of time, longitude, and latitude. The domain of the variable consists of an ordered tuple of *axes* (time, longitude, and latitude). The domain ordering corresponds to the physical ordering of data: the first axis is 'slowest varying'.

An axis is a one-dimensional coordinate vector. Within a dataset, an axis may be shared by more than one variable. An axis may identified as spatio-temporal: a time, vertical level, latitude, or longitude axis.

CDMS allows generalization of domains to include *grids*. In spatial terms, a *grid* is a horizontal partitioning of all or a portion of the Earth's surface. A grid which can be represented as a pair of axes (latitude, longitude) is called a *RectGrid*. For example, if the domain of a variable is (time, latitude, longitude), it can also be represented as (time, grid), where grid is the RectGrid

(latitude, longitude). This representation allows applications to be generalized to non-rectilinear grids.

Grid objects are useful in their own right. In CDMS, grid objects are used to create regridder functions, which can interpolate data arrays between grids. A two-dimensional Boolean mask may be associated with a grid, to represent continental regions or areas of missing data.

1.2.4 Xlinks

In CDMS, a dataset may represent data generated by one run of a climate simulation. This leads to a natural grouping of variables by model. In intercomparison studies, it is also useful to group data by variable for multiple models, and to group associated ensemble runs. This can be accomplished using Xlinks.

An *Xlink* is a pointer to an object in another dataset, or to a dataset itself. An Xlink can represent any CDMS object other than another Xlink.

1.3 Partitioned Datasets

A dataset consists of an ASCII metafile in CDML (XML) format, together with one or more physical datafiles. If a dataset consists of more than one physical datafile, it is said to be *partitioned*. The information describing how the data is spread over multiple datafiles is stored in the metafile as attributes of the dataset and relevant coordinate axes. This consists of three pieces of information: a *file template*, a *directory*, and a *partition* attribute. The directory is an absolute pathname of the root directory of the dataset. The file template is a pathname which is relative to the directory. The partition is a list of indices which describe exactly where along a given coordinate axis a dataset is partitioned.

Most data in CDMS is spatio-temporal data. The axes of variable objects relate to time, longitude, latitude, and vertical levels. It is convenient to partition datasets on the coordinate values of these axes. In CDMS, a dataset can be partitioned on at most two axes: time and/or vertical level. Addition-

ally, the variables in a dataset can be contained in separate datafiles, or can be grouped together.

1.3.1 File Template

A *file template* is a string which serves as the template for the datafile pathnames. It is a relative pathname which contains one or more template specifiers describing which axes are partitioned and, for time axes, which time components (year, month, day, hour, minute, second) are part of the file name.

For example, suppose that a dataset consists of monthly mean variables, for years 1980 through 1989 inclusive. The time axis has length 120 (10 years x 12 monthly means/year). The dataset contains three variables: ta, u, and v. The dataset is partitioned into 36 files such that each datafile contains one year of data for one variable. The file names are:

```
sample_ta_1980.nc
sample_u_1980.nc
sample_v_1980.nc
sample_ta_1981.nc
sample_u_1981.nc
...
sample_ta_1989.nc
sample_u_1989.nc
sample_v_1989.nc
```

The file template for this dataset is

```
sample_%v_%Y.nc
```

%v is the specifier for variable name, and **%Y** is the specifier for the year. Table 2.23 on page 49 gives the complete list of template specifiers.

All datasets have a **.template** attribute, having the template string as value. Optionally, a variable may have a **.template** attribute as well, overriding the dataset template.

1.3.2 Partition

One more piece of information is required to fully describe the dataset partitioning: the partition attribute. Each axis which is partitioned has a **.partition** attribute, which is a list of the start and end indices of each axis partition.

FIGURE 1. Partitioned axis

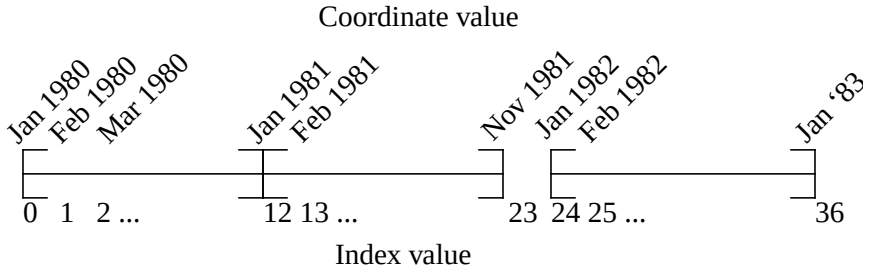


Figure 1 shows a time axis, representing the 36 months January, 1980 through December, 1982, with December 1981 missing. The first partition interval is (0,12), the second is (12,23), and the third is (24,36), where the interval (i,j) represents all indices k such that i <= k < j. The .partition attribute for this axis would be the list:

```
[0, 12, 12, 23, 24, 36]
```

Note that the end index of the second interval is strictly less than the start index of the following interval. This indicates that data for that period is missing.

CHAPTER 2

CDMS Python Application Programming Interface

2.1 Overview

This chapter describes the CDMS Python application programming interface (API). Python is a popular public-domain, object-oriented language. Its features include support for object-oriented development, a rich set of programming constructs, and an extensible architecture. CDMS itself is implemented in a mixture of C and Python. In this chapter the assumption is made that the reader is familiar with the basic features of the Python language.

Python supports the notion of a **module**, the biggest program unit in the language. Modules group together associated classes and methods, and provide a separate namespace. The **import** command makes the module accessible to an application. This chapter documents the **cdms** module.

The chapter sections correspond to the CDMS classes. Each section contains tables describing the class internal (non-persistent) attributes, constructors (functions for creating an object), and class methods. Method datatypes may be any of the Python types:

Table 2.1 Python types used in CDMS

Type	Description
Array	Numeric multidimensional data array. All elements of the array are of the same type. Defined in the **Numeric** module.
Comptime	Absolute time value, a time with representation (year, month, day, hour, minute, second). Defined in the **cdtime** module. cf. **reltime**
Dictionary	An unordered collection of objects, indexed by key. All dictionaries in CDMS are indexed by strings, e.g.: `axes['time']`
Float	Floating-point value.
Integer	Integer value.
List	An ordered sequence of objects, which need not be of the same type. New members can be inserted or appended. Lists are denoted with square brackets, e.g., `[1, 2.0, 'x', y']`
None	No value returned.
Reltime	Relative time value, a time with representation (value, "units since basetime"). Defined in the **cdtime** module. cf. **comptime**
Tuple	An ordered sequence of objects, which need not be of the same type. Unlike lists, tuples elements cannot be inserted or appended. Tuples are denoted with parentheses, e.g., `(1, 2.0, 'x', y')`

2.2 A first example

The following Python script reads January and July monthly temperature data from an input dataset, averages over time, and writes the results to an output file. The input temperature data is ordered (time, latitude, longitude).

```
 1  #!/usr/local/bin/python
 2  import cdms, Numeric
 3  jones = cdms.openDataset('/pcmdi/cdms/obs/jones_mo.xml','r')
 4  tasvar = jones.variables['tas']
 5  jans = tasvar[0::12]
 6  julys = tasvar[6::12]
 7  janavg = Numeric.avg.reduce(jans)
 8  julyavg = Numeric.avg.reduce(julys)
 9  out = cdms.createDataset('janjuly.nc')
10  grid = tasvar.getGrid()
11  outgrid = out.copyGrid(grid)
12  janvar = out.createVariable('tas_jan', cdms.CdFloat,
        (outgrid,))
13  julyvar = out.createVariable('tas_jul', cdms.CdFloat,
        (outgrid,))
14  janvar.units = julyvar.units = "K"
15  janvar.long_name = "mean January surface temperature"
16  julyvar.long_name = "mean July surface temperature"
17  janvar[:] = janavg
18  julyvar[:] = julyavg
19  jones.close()
20  out.close()
```

Line	Notes
2	Makes the CDMS and Numeric modules available.
3	Opens the input dataset, read-only. The `.xml` file is an ASCII file which describes the data files in the dataset. The result `jones` is a dataset object.

Line	Notes
4	Gets the surface air temperature variable. **`'tas'`** is the name of the variable in the input dataset. **`jones.variables`** is a Python dictionary, which maps the variable name (**`'tas'`**) to the variable object (**`tasvar`**).
5	Reads all January monthly mean data into a Numeric array **`jans`**. Variables can be sliced as if they were Numeric arrays. The slice operator **`[0::12]`** means 'take every 12th slice from dimension 0, starting at index 0 and ending at the last index.' If the stride **`12`** were omitted, it would default to 1. Note that the variable is actually 3-dimensional. Since no slice is specified for the second or third dimensions, all values of those dimensions are retrieved. The slice could also have been written **`[0::12, : , :]`**. Also note that the data may be read from multiple data files, depending on the organization of the dataset. CDMS opens the needed data files, extracts the appropriate slices, and concatenates them into the result array as necessary.
6	Reads all July data into a Numeric array **`julys`**.
7	Averages **`jans`** across the first array dimension, time. The result is a function of latitude and longitude.
8	Averages **`julys`** across time.
9	Creates a new netCDF output file named **`'janjuly.nc'`** to hold the results.
10	Gets the grid object **`grid`** associated with **`tasvar`**, contained in the input dataset.
11	Copies **`grid`** to the output file. **`outgrid`** is a grid object contained in the output file.

Line	Notes
12	Creates a variable **`janvar`** in the output file, as a function of the output grid. Its identifier in the output file is the string **`'tas_jan'`**. The last argument is a tuple of the grids and/or axes which define the domain of the variable. Note that as yet no data has been written to the file.
13	Creates a new variable **`julyvar`** in the output file.
14	Creates a **`.units`** attribute for both variables, and writes the string value **`'K'`** to the output file. There is nothing special about **`.units`**; any attribute can be created and written in similar fashion. Global attributes are written by setting an attribute of the file object.
17	Writes the January average data to the output file. Setting a slice of a variable writes data to that variable. In this case, the slice [:] references all data for the variable.
18	Writes July average data to the output file.
19	Closes the input dataset.
20	Closes the output file.

2.3 cdms module

The **cdms** module is the Python interface to CDMS. The objects and methods in this chapter are made accessible with the command:

```
import cdms
```

The functions described in this section are not associated with a class. Rather, they are called as module functions, e.g.,

```
file = cdms.createDataset('sample.nc')
```

Table 2.2 cdms module functions

Type	Definition
Axis	**createAxis(data, bounds=None):** Create an Axis, which is not associated with a file or dataset. This is useful for creating a grid which is not contained in a file or dataset. *data* is a one-dimensional, monotonic Numeric array. *bounds* is an array of shape (len(data),2), such that for all i, data[i] is in the range [bounds[i,0],bounds[i,1]]. Also see: CdmsFile.createAxis
Dataset or CdmsFile	**createDataset(path,template=None)** Create a Dataset or CdmsFile. **(Note: Only CdmsFile creation is implemented at present.)** *path* is the XML file name, or netCDF filename for simple file create. If the path extension is '.xml' or '.cdml', a Dataset is created. Otherwise a netCDF CdmsFile is created. *template* is a string filename template for the datafile(s), for dataset creation. This argument should be omitted for CdmsFile creation. **Example**: Create a new netCDF file. `file = cdms.createDataset('sample.nc')`
Axis	**createEqualAreaAxis(nlat)** Create an equal-area latitude axis. The latitude values range from north to south, and for all axis values x[i], sin(x[i])-sin(x[i+1]) is constant. *nlat* is the axis length. The axis is not associated with a file or dataset.

Table 2.2 cdms module functions

Type	Definition
Axis	**createGaussianAxis(nlat)** Create a Gaussian latitude axis. Axis values range from north to south. *nlat* is the axis length. The axis is not associated with a file or dataset.
RectGrid	**createGenericGrid(latArray, lonArray, latBounds=None, lonBounds=None, order="yx", mask=None)** Create a generic grid, that is, a grid which is not typed as Gaussian, uniform, or equal-area. The grid is not associated with a file or dataset. *latArray* is a NumPy array of latitude values. *lonArray* is a NumPy array of longitude values *latBounds* is a NumPy array having shape (len(latArray),2), of latitude boundaries. *lonBounds* is a NumPy array having shape (len(lonArray),2), of longitude boundaries. *order* is a string specifying the order of the axes, either “yx” for (latitude, longitude), or “xy” for the reverse. *mask* (optional) is an integer-valued NumPy mask array, having the same shape and ordering as the grid.
RectGrid	**createGlobalMeanGrid(grid)** Generate a grid for calculating the global mean via a regridding operation. The return grid is a single zone covering the range of the input grid. *grid* is a RectGrid.

Table 2.2 cdms module functions

Type	Definition
RectGrid	**createRectGrid(lat, lon, order, type="generic", mask=None)** Create a rectilinear grid, not associated with a file or dataset. This might be used as the target grid for a regridding operation. *lat* is a latitude axis, created by cdms.createAxis. *lon* is a longitude axis, created by cdms.createAxis. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). *type* is one of ’gaussian’,’uniform’,’equalarea’,or ’generic’ If specified, *mask* is a two-dimensional, logical Numeric array (all values are zero or one) with the same shape as the grid.
RectGrid	**createUniformGrid(startLat, nlat, deltaLat, startLon, nlon, deltaLon, order="yx", mask=None)** Create a uniform rectilinear grid. The grid is not associated with a file or dataset. The grid boundaries are at the midpoints of the axis values. *startLat* is the starting latitude value. *nlat* is the number of latitudes. *deltaLat* is the increment between latitudes. *startLon* is the starting longitude value. *nlon* is the number of longitudes. *deltaLon* is the increment between longitudes. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). If specified, *mask* is a two-dimensional, logical Numeric array (all values are zero or one) with the same shape as the grid.

Table 2.2 cdms module functions

Type	Definition
Axis	**createUniformLatitudeAxis(startLat, nlat, deltaLat)** Create a uniform latitude axis. The axis boundaries are at the midpoints of the axis values. The axis is designated as a circular latitude axis. *startLat* is the starting latitude value. *nlat* is the number of latitudes. *deltaLat* is the increment between latitudes.
RectGrid	**createZonalGrid(grid)** Create a zonal grid. The output grid has the same latitude as the input grid, and a single longitude. This may be used to calculate zonal averages via a regridding operation. *grid* is a RectGrid.
Axis	**createUniformLongitudeAxis(startLon, nlon, deltaLon)** Create a uniform longitude axis. The axis boundaries are at the midpoints of the axis values. The axis is designated as a circular longitude axis. *startLon* is the starting longitude value. *nlon* is the number of longitudes. *deltaLon* is the increment between longitudes.

Table 2.2 cdms module functions

Type	Definition
Dataset or CdmsFile	**openDataset(url,mode='r',template=None)** Open or create a Dataset or CdmsFile. *url* is a Uniform Resource Locator, referring to a cdunif or XML file. If the URL has the extension '.xml' or '.cdml', a Dataset is returned, otherwise a CdmsFile is returned. If the URL protocol is 'http', the file must be a '.xml' or '.cdml' file, and the mode must be 'r'. If the protocal is 'file' or is omitted, a local file or dataset is opened. *mode* is the open mode. See Table 2.22 on page 49. *template* is a string file template for the datafile(s), for dataset creation. This argument should be omitted except for Dataset creation. **Example**: `f = cdms.openDataset("sampleset.xml")`
None	**setAutoBounds(mode)** Set autobounds mode. If *mode* is 'on' (the default), getBounds will automatically generate boundary information for an axis or grid, if the boundaries are not explicitly defined. If *mode* is'off', and no boundary data is explicitly defined, the bounds will NOT be generated; getBounds will return None for the boundaries.

Table 2.2 cdms module functions

Type	Definition
None	**setAutoReshapeMode(mode)** If *mode* is ‘on’, remove singleton dimensions from all arrays returned by slice operators or **Variable.getRegion()**. The default mode is ‘off’. The autoreshape mode may be changed at any time. Note: Enabling autoreshape causes non-contiguous arrays to be copied to contiguous arrays. This will incur some CPU overhead. **Example**: Enable autoreshape mode. `cdms.setAutoReshapeMode('on')`
None	**setClassifyGrids(mode)** Set grid classifiction mode. This affects how grid type is determined, for the purpose of generating grid boundaries. If mode is ‘on’ (the default), grid type is determined by a grid classification method, regardless of the value of grid.getType(). If mode is ’off’, the value of grid.getType() determines the grid type

Table 2.3 Class Tags

Tag	Class
'axis'	Axis
‘database’	Database
'dataset'	Dataset, CdmsFile
'grid'	RectGrid
'variable'	Variable
'xlink'	Xlink

2.4 CdmsObj

A CdmsObj is the base class for all CDMS database objects. At the application level, CdmsObj objects are never created and used directly. Rather the subclasses of CdmsObj (Dataset, Variable, Axis, etc.) are the basis of user application programming.

All objects derived from CdmsObj have a special attribute **.attributes**. This is a Python dictionary, which contains all the external (persistent) attributes associated with the object. This is in contrast to the internal, non-persistent attributes of an object, which are built-in and predefined.

Example: get a list of all external attributes of obj.

```
extatts = obj.attributes.keys()
```

Table 2.4 Attributes common to all CDMS objects

Type	Name	Definition
Dictionary	attributes	External attribute dictionary for this object.

All attributes may be accessed and set using the Python dot notation (**'.'**)

Table 2.5 Getting and setting attributes

Type	Definition
Various	**value = obj.attname** Get an internal or external attribute value. If the attribute is external, it is read from the database. If the attribute is not already in the database, it is created as an external attribute. Internal attributes cannot be created, only referenced.

Table 2.5 Getting and setting attributes

Type	Definition
	obj.attname = value Set an internal or external attribute value. If the attribute is external, it is written to the database.

2.5 *Axis*

An Axis is a one-dimensional coordinate object.

An Axis is contained in a Dataset. Setting a slice of an Axis writes data to the Dataset, referencing an Axis slice reads data from the Dataset. Axis objects are also used to define the domain of a Variable.

An axis in a CdmsFile may be designated the ‘unlimited’ axis, meaning that it can be extended in length after the initial definition. There can be at most one unlimited axis associated with a CdmsFile.

Table 2.6 Axis Internal Attributes

Type	Name	Definition
Dictionary	attributes	External attribute dictionary.
String	id	Axis identifer.
Dataset	parent	The dataset which contains the variable.
Tuple	shape	The length of each axis.

Table 2.7 Axis Constructors

cdms.createAxis(data, bounds=None)

Create an axis which is not associated with a dataset or file. See Table 2.2 on page 18.

Dataset.createAxis(name,ar)

Create an Axis in a Dataset. (**This function is not yet implemented.**)

CdmsFile.createAxis(name,ar,unlimited=0)

Create an Axis in a CdmsFile.

name is the string name of the Axis.

ar is a 1-D data array which defines the Axis values. It may have the value None if an unlimited axis is being defined.

At most one Axis in a CdmsFile may be designated as being ‘unlimited’, meaning that it may be extended in length. To define an axis as unlimited, either:

- set ar to None, and leave *unlimited* undefined, or
- set ar to the initial 1-D array, and set *unlimited* to **cdms.Unlimited**

Table 2.8 Axis Methods

Type	Method Definition
Array	**array = axis[i:j]** Read a slice of data from the external dataset. Data is returned in the physical ordering defined in the dataset. See Table 2.9 on page 32 for a description of slice operators.

Table 2.8 Axis Methods

Type	Method Definition
None	**axis[i:j] = array** Write a slice of data to the external dataset. **(axes in CdmsFiles only)**
None	**assignValue(array)** Set the entire value of the axis. *array* is a one-dimensional, Numeric array.
None	**designateCircular(modulo, persistent=0)** Designate the axis to be circular. *modulo* is the modulus value. Any given axis value x is treated as equivalent to x+modulus If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary.
None	**designateLatitude(persistent=0):** Designate the axis to be a latitude axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary.
None	**designateLevel(persistent=0)** Designate the axis to be a vertical level axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary.
None	**designateLongitude(persistent=0, modulo=360.0)** Designate the axis to be a longitude axis. *modulo* is the modulus value. Any given axis value x is treated as equivalent to x+modulus If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary.

Table 2.8 Axis Methods

Type	Method Definition
None	**designateTime(persistent=0, calendar = cdtime.GregorianCalendar)** Designate the axis to be a time axis. If *persistent* is true, the external file or dataset (if any) is modified. By default, the designation is temporary. *calendar* is defined as in **getCalendar()**.
Array	**getBounds()** Get the associated boundary array. The boundary array has shape (n,2), where n is the length of the axis. If a boundary array is not explicitly defined and autoBounds mode is on, a default array is generated by calling genGenericBounds. Otherwise if autoBounds mode is off, the return value is None. See **setAutoBoundsMode**.
Integer	**getCalendar()** Returns the calendar associated with the (time) axis. Possible return values, as defined in the cdtime module, are: • cdtime.GregorianCalendar: the standard Gregorian calendar • cdtime.JulianCalendar: years divisible by 4 are leap years • cdtime.NoLeapCalendar: a year is 365 days • cdtime.Calendar360: a year is 360 days • None: no calendar can be identified Note: If the axis is not a time axis, the global, file-related calendar is returned.
Array	**getValue()** Get the entire axis vector.

Table 2.8 Axis Methods

Type	Method Definition
Integer	**isCircular()** Returns true if the axis has circular topology. An axis is defined as circular if: • axis.topology==’circular’, or • axis.topology is undefined, and the axis is a longitude The default cycle for circular axes is 360.0
Integer	**isLatitude()** Returns true iff the axis is a latitude axis.
Integer	**isLevel()** Returns true iff the axis is a level axis.
Integer	**isLinear()** Returns true iff the axis has a linear representation.
Integer	**isLongitude()** Returns true iff the axis is a longitude axis.
Integer	**isTime()** Returns true iff the axis is a time axis.
Integer	**len(axis)** The length of the axis.

Table 2.8 Axis Methods

Type	Method Definition
Tuple	**mapInterval(interval)** Map a coordinate interval to an index interval. *interval* is a tuple having one of the forms: (x,y) (x,y,indicator) (x,y,indicator,cycle) None or ':' where *x* and *y* are coordinates indicating the interval [x,y), and: *indicator* is a two-character string, where the first character is 'c' if the interval is closed on the left, 'o' if open, and the second character has the same meaning for the right-hand point. (Default: 'co') If *cycle* is specified, the axis is treated as circular with the given cycle value. By default, if axis.isCircular() is true, the axis is treated as circular with a default value of 360.0. An interval of None or ':' returns the full index interval of the axis. **(continued)**

Table 2.8 Axis Methods

Type	Method Definition
	(mapInterval, continued) The method returns the corresponding index interval [i,j), where i<j, indicating the half-open index interval i<=k<j, or None if the intersection is empty. Note: if the interval is interior to the axis, but does not span any axis element, a singleton (i,i+1) indicating an adjacent index is returned. For an axis which is circular (axis.topology == 'circular'), [i,j) is interpreted as follows (where N = len(axis)): • if j <= N, the interval does not wrap around the axis endpoint • if j > N, the interval wraps around, and is equivalent to the two consecutive index intervals [i,N), [0,j-N) **See also**: **Variable.getRegion()**
None	**setBounds(bounds, persistent=0)** Set the boundary array. *bounds* is a NumPy array bnds of shape (len(axis),2), such that the boundaries of the nth axis value are [bnds[n,0],bnds[n,1]]. Note: By default, the boundaries are not written to the file or dataset containing the axis (if any). This allows bounds to be set on read-only files, for regridding. If the optional argument *persistent* is set to 1, the boundary array is written to the file.
None	**setCalendar(calendar, persistent=1)** Set the calendar for this (time) axis. *calendar* is defined as in getCalendar(). If *persistent* is true, the external file or dataset (if any) is modified. This is the default.

Table 2.8 Axis Methods

Type	Method Definition
Axis	**subaxis(i,j)** Create an axis associated with the integer range [i:j]. The result axis is not associated with a file or dataset.
String	**typecode()** The Numeric datatype identifier.

Table 2.9 Axis Slice Operators

Slice	Definition
[i]	The ith element, starting with index 0
[i:j]	The ith element through, but not including, element j
[i:]	The ith element through and including the end
[:j]	The beginning element through, but not including, element j
[:]	The entire array
[i:j:k]	Every kth element, starting at i, through but not including j
[-i]	The ith element from the end. -1 is the last element.

Example: A longitude axis has value [0.0, 2.0, ..., 358.0], of length 180. Map the coordinate interval -5.0 <= x < 5.0 to index interval(s), with wrap-around. The result index interval 178<=k<183 wraps around, since 180<183. This is equivalent to the two index intervals 178<=k<180 and 0<=k<3

```
> axis.isCircular()
1
> axis.mapInterval((-5.0,5.0))
(178,183)
>
```

2.6 CdmsFile

A CdmsFile is a physical file, accessible via the cdunif interface. netCDF files are accessible in read-write mode. All other formats (DRS, HDF, GrADS/GRIB, POP, QL) are accessible read-only.

Table 2.10 CdmsFile Internal Attributes

Type	Name	Definition
Dictionary	attributes	Global, external file attributes
Dictionary	axes	Axis objects contained in the file.
Dictionary	grids	Grids contained in the file.
String	id	File pathname.
Dictionary	variables	Variables contained in the file.

Table 2.11 CdmsFile Constructors

cdms.openDataset(path, mode)

Open the file specified by path.

path is the file pathname, a string.

mode is the open mode indicator, as listed in Table 2.22 on page 49.

cdms.createDataset(path)

Create the file specified by *path*, a string.

Table 2.12 CdmsFile Methods

Type	Definition
None	**close()** Close the file.
Axis	**copyAxis(axis, newname=None)** Copy axis values and attributes to a new axis in the file. The returned object is persistent: it can be used to write axis data to or read axis data from the file. If an axis already exists in the file, having the same name and coordinate values, it is returned. It is an error if an axis of the same name exists, but with different coordinate values. *axis* is the axis object to be copied. *newname*, if specified, is the string identifier of the new axis object. If not specified, the identifier of the input axis is used.
Grid	**copyGrid(grid, newname=None)** Copy grid values and attributes to a new grid in the file. The returned grid is persistent. If a grid already exists in the file, having the same name and axes, it is returned. An error is raised if a grid of the same name exists, having different axes. *grid* is the grid object to be copied. *newname*, if specified is the string identifier of the new grid object. If unspecified, the identifier of the input grid is used.
Axis	**createAxis(String id, Array ar, Integer unlimited=0)** Create a new Axis. This is a persistent object which can be used to read or write axis data to the file. *ar* is the one-dimensional axis array. Set *unlimited* to cdms.Unlimited to indicate that the axis is extensible.

Table 2.12 CdmsFile Methods

Type	Definition
RectGrid	**createRectGrid(id, lat, lon, order, type="generic", mask=None)** Create a RectGrid in the file. This is not a persistent object: the order, type, and mask are not written to the file. However, the grid may be used for regridding operations. *lat* is a latitude axis in the file. *lon* is a longitude axis in the file. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). *type* is one of ’gaussian’,’uniform’,’equalarea’,or ’generic’ If specified, *mask* is a two-dimensional, logical Numeric array (all values are zero or one) with the same shape as the grid.
Variable	**createVariable(String id, String datatype,List axes)** Create a new Variable. This is a persistent object which can be used to read or write variable data to the file. *id* is a String name which is unique with respect to all other objects in the file. *datatype* is a CDMS datatype, as listed in Table 2.13 on page 36. *axes* is a list of Axis and/or Grid objects.
Variable	**createVariableCopy(var, newname=None)** Create a new Variable, with the same name, axes, and attributes as the input variable. An error is raised if a variable of the same name exists in the file. *var* is the Variable to be copied. *newname*, if specified is the name of the new variable. If unspecified, the returned variable has the same name as *var*. Note: Unlike copyAxis, the actual data is not copied to the new variable.

Table 2.12 CdmsFile Methods

Type	Definition
None	**sync()** Writes any pending changes to the file.

Table 2.13 CDMS Datatypes

CDMS Datatype	Definition
CdChar	character
CdDouble	double-precision floating-point
CdFloat	floating-point
CdInt	integer
CdLong	long integer
CdShort	short integer

2.7 Database

A Database is a collection of datasets and other CDMS objects. It consists of a hierarchical collection of objects, with the database being at the root, or top of the hierarchy. A database is used to:

- search for metadata
- access data
- provide authentication and access control for data and metadata

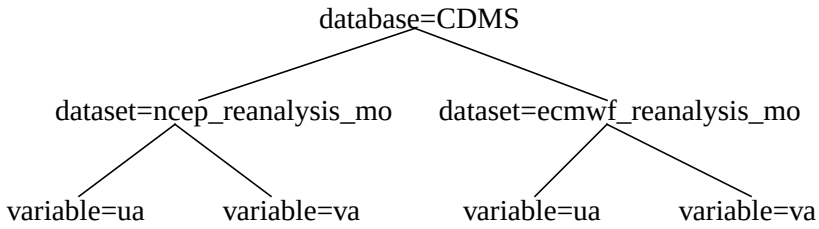
The figure below illustrates several important points:

- Each object in the database has a *relative name* of the form *tag=id*. The id of an object is unique with respect to all objects contained in the parent.

- The *name* of the object consists of its relative name followed by the relative name(s) of its antecedent objects, up to and including the database name. In the figure below, one of the variables has name

  “variable=ua, dataset=ncep_reanalysis_mo,database=CDMS”.

- Subordinate objects are thought of as being contained in the parent. In this example, the database ‘CDMS’ contains two datasets, each of which contain several variables.



2.7.1 Overview

To access a database:

1. Open a connection. The **connect** method opens a database connection. **connect** takes a database URI and returns a database object:
   ```
   db = cdms.connect(“ldap://dbhost.llnl.gov/
       database=CDMS,ou=PCMDI,o=LLNL,c=US”)
   ```
2. Search the database, locating one or more datasets, variables, and/or other objects.

The database **searchFilter** method searches the database. A single database connection may be used for an arbitrary number of searches.

For example, to find all observed datasets:

```
result = db.searchFilter("category=observed",tag=”dataset”)
```

Searches can be restricted to a subhierarchy of the database. This example searches just the dataset ‘ncep_reanalysis_mo’:

```
result = db.searchFilter(relbase="dataset=ncep_reanalysis")
```

3. Refine the search results if necessary. The result of a search can be narrowed with the **searchPredicate** method.
4. Process the results. A search result consists of a sequence of entries. Each entry has a name, the name of the CDMS object, and an attribute dictionary, consisting of the attributes located by the search:
```
for entry in result:
    print entry.name, entry.attributes
```
5. Access the data. The CDMS object associated with an entry is obtained from the **getObject** method:
```
obj = entry.getObject()
```

If the id of a dataset is known, the dataset can be opened directly with the **openDataset** method:

```
dset = db.openDataset("ncep_reanalysis_mo")
```

6. Close the database connection:
```
db.close()
```

Table 2.14 Database Internal Attributes

Type	Name	Summary
Dictionary	attributes	Database attribute dictionary
LDAP	db	(LDAP only) LDAP database object
String	netloc	Hostname, for server-based databases
String	path	path name
String	uri	Uniform Resource Identifier.

Table 2.15 Database Constructors

db = cdms.connect(uri=None, user="", password="")

Connect to the database.

uri is the Universal Resource Indentifier of the database. The form of the URI depends on the implementation of the database. For a Lightweight Directory Access Protocol (LDAP) database, the form is:

```
ldap://host[:port]/dbname
```

For example, if the database is located on host ‘dbhost.llnl.gov’, and is named ‘database=CDMS,ou=PCMDI,o=LLNL,c=US’, the URI is:

```
ldap://dbhost.llnl.gov/database=CDMS,ou=PCMDI,o=LLNL,c=US
```

If unspecified, the URI defaults to the value of environment variable **CDMSROOT**.

user is the user ID. If unspecified, an anonymous connection is made.

password is the user password. A password is not required for an anonymous connection.

Table 2.16 Database Methods

Type	Definition
None	**close()** Close a database connection.

Table 2.16 Database Methods

Type	Definition
Dataset	**openDataset(dsetid, mode='r')** Open a dataset. *dsetid* is the string dataset identifier *mode* is the open mode, 'r' - read-only, 'r+' - read-write, 'w' - create.

Table 2.16 Database Methods

Type	Definition

SearchResult	**searchFilter(filter=None, tag=None, relbase=None, scope=Subtree, attnames=None, timeout=None)**
	Search a CDMS database.
	filter is the string search filter. Simple filters have the form "tag = value". Simple filters can be combined using logical operators ’&’, ’|’, ’!’ in prefix notation. For example, the filter ’(&(objectclass=variable)(id=cli))’ finds all variables named “cli”. A formal definition of search filters is provided in the following section.
	tag restricts the search to objects with that tag ("dataset" | "variable" | "database" | "axis" | "grid").
	relbase is the relative name of the base object of the search. The search is restricted to the base object and all objects below it in the hierarchy. For example, to search only dataset ‘ncep_reanalysis_mo’, specify:
	`relbase=”dataset=ncep_reanalysis_mo”.`
	To search only variable ‘ua’ in ncep_reanalysis_mo, use:
	`relbase=”variable=ua, dataset=ncep_reanalysis_mo”`
	If no base is specified, the entire database is searched. See the *scope* argument also.
	scope is the search scope (**Subtree** | **Onelevel** | **Base**). **Subtree** searches the base object and its descendants. **Onelevel** searches the base object and its immediate descendants. **Base** searches the base object alone. The default is **Subtree**.
	attnames: list of attribute names. Restricts the attributes returned. If None, all attributes are returned. Attributes ‘id’ and ‘objectclass’ are always included in the list.
	timeout: integer number of seconds before timeout. The default is no timeout.

2.7.2 Searching a database

The **searchFilter** method is used to search a database. The result is called a *search result*, and consists of a sequence of *result entries*.

In its simplest form, **searchFilter** takes an argument consisting of a string filter. The search returns a sequence of entries, corresponding to those objects having an attribute which matches the filter. Simple filters have the form (*tag = value)*, where *value* can contain wildcards. For example:

```
'(id = ncep*)'
'(project = AMIP2)'
```

Simple filters can be combined with the logical operators '&', '|', '!'. For example,

```
'(&(id = bmrc*)(project = AMIP2))'
```

matches all objects with id starting with 'bmrc', and a 'project' attribute with value 'AMIP2'.

Formally, search filters are strings defined as follows:

```
filter     ::=   "(" filtercomp ")"
filtercomp ::=   "&" filterlist | # and
                 "|" filterlist | # or
                 "!" filterlist | # not
                 simple
filterlist ::= filter | filter filterlist
simple     ::= tag op value
op         ::=   "="  | # equality
                 "~=" | # approximate equality
                 "<=" | # lexicographically less than or equal to
                 ">="   # lexicographically greater than or equal to
tag        ::= string attribute name
value      ::= string attribute value, may include '*' as a wild card
```

Attribute names are defined in the chapter on "Climate Data Markup Language (CDML)" on page 91. In addition, some special attributes are defined for convenience:

- **category** is either "experimental" or "observed"
- **parentid** is the ID of the parent dataset

- **project** is a project identifier, e.g., “AMIP2”
- **objectclass** is the list of tags associated with the object.

The set of objects searched is called the search *scope*. The top object in the hierarchy is the *base object*. By default, all objects in the database are searched, that is, the database is the base object. If the database is very large, this may result in an unnecessarily slow or inefficient search. To remedy this the search scope can be limited in several ways:

- The base object can be changed.
- The scope can be limited to the base object and one level below, or to just the base object.
- The search can be restricted to objects of a given class (dataset, variable, etc.)
- The search can be restricted to return only a subset of the object attributes
- The search can be restricted to the result of a previous search.

A search result is accessed sequentially within a for loop:

```
result = db.searchFilter('(&(category=obs*)(id=ncep*))')
for entry in result:
    print entry.name
```

Search results can be narrowed using **searchPredicate**. In the following example, the result of one search is itself searched for all variables defined on a 94x192 grid:

```
>>> result = db.searchFilter('parentid=ncep*',tag="variable")
>>> len(result)
65
>>> result2 = result.searchPredicate(lambda x:
        x.getGrid().shape==(94,192))
>>> len(result2)
3
>>> for entry in result2: print entry.name
variable=rluscs,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
variable=rlds,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
variable=rlus,dataset=ncep_reanalysis_mo,database=CDMS,ou=PCMDI,
        o=LLNL, c=US
>>>
```

Table 2.17 SearchResult Methods

Type	Definition

ResultEntry	**[i]**
	Return the i-th search result. Results can also be returned in a **for** loop:
	`for entry in db.searchResult(tag="dataset"):`
	`    ...`

Integer	**len()** Number of entries in the result.
SearchResult	**searchPredicate(predicate, tag=None)** Refine a search result, with a predicate search. *predicate* is a function which takes a single CDMS object and returns true (1) if the object satisfies the predicate, 0 if not. *tag* restricts the search to objects of the class denoted by the tag. Note: In the current implementation, **searchPredicate** is much less efficient than **searchFilter**. For best performance, use **searchFilter** to narrow the scope of the search, then use **searchPredicate** for more general searches.

A search result is a sequence of result entries. Each entry has a string name, the name of the object in the database hierarchy, and an attribute dictionary. An entry corresponds to an object found by the search, but differs from the object, in that only the attributes requested are associated with the entry. In general, there will be much more information defined for the associated CDMS object, which is retrieved with the **getObject** method.

Table 2.18 ResultEntry Attributes

Type	Name	Summary
String	name	The name of this entry in the database.
Dictionary	attributes	The attributes returned from the search. attributes[key] is a list of all string values associated with the key.

Table 2.19 ResultEntry Methods

Type	Definition
CdmsObj	**getObject()** Return the CDMS object associated with this entry. Note: For many search applications it is unnecessary to access the associated CDMS object. For best performance this function should be used only when necessary, for example, to retrieve data associated with a variable.

2.7.3 Accessing data

To access data via CDMS:

1. Locate the dataset ID. This may involve searching the metadata.
2. Open the dataset, using the openDataset method.
3. Reference the portion of the variable to be read.

In the next example, a portion of variable ‘ua’ is read from dataset ‘ncep_reanalysis_mo’:

```
dset = db.openDataset(‘ncep_reanalysis_mo’)
ua = dset.variables[‘ua’]
data = ua[0,0]
```

2.7.4 Examples of database searches

In the following examples, `db` is the database opened with

```
db = cdms.connect()
```

This defaults to the database defined in environment variable CDMSROOT.

List all variables in dataset ‘ncep_reanalysis_mo’:

```
for entry in db.searchFilter(filter="parentid=ncep_reanalysis_mo",
        tag="variable"):
    print entry.name
```

Find all axes with bounds defined:

```
for entry in db.searchFilter(filter="bounds=*",tag="axis"):
    print entry.name
```

Locate all GDT datasets:

```
for entry in
        db.searchFilter(filter="Conventions=GDT*",tag="dataset"):
    print entry.name
```

Find all variables with missing time values, in observed datasets:

```
def missingTime(obj):
    time = obj.getTime()
    return time.length != time.partition_length

result = db.searchFilter(filter="category=observed")
for entry in result.searchPredicate(missingTime):
    print entry.name
```

Find all CMIP2 datasets having a variable with id "hfss":

```
for entry in
        db.searchFilter(filter="(&(project=CMIP2)(id=hfss))",tag="var
        iable"):
    print entry.getObject().parent.id
```

Find all observed variables on 73x144 grids:

```
result = db.searchFilter('category=obs*')
for entry in result.searchPredicate(lambda x:
        x.getGrid().shape==(73,144),tag="variable"):
    print entry.name
```

Find all observed variables with more than 1000 timepoints:

```
result = db.searchFilter('category=obs*')
for entry in result.searchPredicate(lambda x: len(x.getTime())>1000,
        tag="variable"):
    print entry.name, len(entry.getObject().getTime())
```

Find the total number of each type of object in the database

```
print len(db.searchFilter(tag="database")),"database"
print len(db.searchFilter(tag="dataset")),"datasets"
print len(db.searchFilter(tag="variable")),"variables"
print len(db.searchFilter(tag="axis")),"axes"
```

2.8 Dataset

A Dataset is a virtual file. It consists of a metafile, in CDML/XML representation, and one or more data files.

Table 2.20 Dataset Internal Attributes

Type	Name	Summary
Dictionary	attributes	Dataset external attributes.
Dictionary	axes	Axes contained in the dataset.
String	datapath	Path of data files, relative to the parent database. If no parent, the datapath is absolute.
Dictionary	grids	Grids contained in the dataset.

Table 2.20 Dataset Internal Attributes

Type	Name	Summary
String	id	Dataset identifier.
String	mode	Open mode.
Database	parent	Database which contains this dataset. If the dataset is not part of a database, the value is None.
String	uri	Uniform Resource Identifier of this dataset.
Dictionary	variables	Variables contained in the dataset.
Dictionary	xlinks	External links contained in the dataset.

Table 2.21 Dataset Constructors

cdms.openDataset(String uri, String mode='r')

Open the dataset specified by the Universal Resource Indicator, a CDML file. mode is one of the indicators listed in Table 2.22 on page 49.

cdms.createDataset(String path, String directory, String fileTemplate)

(Note: this function is not yet implemented)

Create a new dataset. *path* is the filepath of a CDML file. *fileTemplate* describes how the dataset is to be partitioned. It is a pathname, relative to the directory, which contains zero or more template specifiers (see Table 2.23 on page 49). A template may contain directory names as well as file names. A template specifier is a string of the form '%X' or '%eX', where X is one of the characters listed Table 2.23 on page 49. The form '%eX' may be used to specify the end time or level value. A specifier may appear more than once in a template.

Table 2.22 Open Modes

Mode	Definition
'r'	read-only
'r+'	read-write
'a'	read-write. Open the file if it exists, otherwise create a new file
'w'	Create a new file, read-write

Table 2.23 Template Specifiers

Specifier	Definition	Example
d	day number	1 .. 31
g	month, lower case, three characters	'jan', 'feb', ...
G	month, upper case, three characters	'JAN', 'FEB', ...
H	hour	0 .. 23
L	vertical level	integer
m	month number, not zero filled	1 .. 12
M	minute	0 .. 59
n	month number, two-digit, zero-filled	01, 02, ..., 12
S	second	0 .. 59
v	variable ID	character
y	year, two-digit, zero-filled	integer
Y	year	integer
z	Zulu time	ex: '6Z19990201'
%	percent sign	'%'

For example, the file template

```
ccsr-a/mo/%v/ccsr-a/%v_ccsr-a_%Y.%n-%eY.%en.nc
```

contains the specifiers **%v** (variable name), **%Y** (year), **%eY** (end year), and **%en** (end month). One of the files in the dataset might have the path (relative to the parent directory)

```
ccsr-a/mo/ta/ccsr-a/ta_ccsr-a_1979.01-1979.12.nc
```

Table 2.24 Dataset Methods

Type	Definition
None	**close()** Close the dataset. **createRectGrid(id, lat, lon, order, type="generic", mask=None)** Create a RectGrid in the dataset. This is not a persistent object: the order, type, and mask are not written to the dataset. However, the grid may be used for regridding operations. *lat* is a latitude axis in the dataset. *lon* is a longitude axis in the dataset. *order* is a string with value “yx” (the first grid dimension is latitude) or “xy” (the first grid dimension is longitude). *type* is one of ’gaussian’,’uniform’,’equalarea’,or ’generic’ If specified, *mask* is a two-dimensional, logical Numeric array (all values are zero or one) with the same shape as the grid.

Table 2.24 Dataset Methods

Type	Definition
List	**getPaths()** Get a sorted list of pathnames of datafiles which comprise the dataset. This does not include the XML metafile path, which is stored in the **.uri** attribute.
None	**sync()** Write any pending changes to the dataset.

2.9 RectGrid

A RectGrid is a two-dimensional, horizontal, rectilinear grid. A rectGrid can be defined in terms of a pair of axes, one longitude and one latitude. A two-dimensional, logical mask array may optionally be associated with a rectGrid.

Table 2.25 RectGrid Internal Attributes

Type	Name	Definition
Dictionary	attributes	External attribute dictionary.
String	id	The grid identifier.
Dataset or CdmsFile	parent	The dataset or file which contains the grid.
Tuple	shape	The shape of the grid, a 2-tuple.

Table 2.26 RectGrid Constructors

cdms.createRectGrid(lat, lon, order, type="generic", mask=None)

Create a grid not associated with a file or dataset.

See Table 2.2 on page 18.

CdmsFile.createRectGrid(id, lat, lon, order, type="generic", mask=None)

Create a grid associated with a file. See Table 2.12 on page 34.

Dataset.createRectGrid(id, lat, lon, order, type="generic", mask=None)

Create a grid associated with a dataset. See Table 2.24 on page 50.

Table 2.27 RectGrid Methods

Type	Definition
Axis	**getAxis(Integer n)** Get the n-th axis. n is either 0 or 1.

Table 2.27 RectGrid Methods

Type	Definition
Tuple	**getBounds()** Get the grid boundary arrays. Returns a tuple (latitudeArray, longitudeArray), where latitudeArray is a Numeric array of latitude bounds, with shape (n,2), and longitudeArray is a similar array for longitude bounds. If no boundary arrays are explicitly defined (in the file or dataset), the result depends on the autoBounds mode (see **cdms.setAutoBounds**) and the grid classification mode (see **cdms.setClassifyGrids**). By default, autoBounds mode is enabled, in which case the boundary arrays are generated based on the type of grid. If disabled, the return value is (None,None). The grid classification mode specifies how the grid type is to be determined. By default, the grid type (Gaussian, uniform, etc.) is determined by calling **grid.classifyInFamily.** If the mode is 'off' **grid.getType** is used instead
Axis	**getLatitude()** Get the latitude axis of this grid.
Axis	**getLongitude()** Get the latitude axis of this grid.
Array	**getMask()** Get the mask array of this grid, if any. Returns a 2-D Numeric array, having the same shape as the grid. If the mask is not explicitly defined, the return value is None.
String	**getOrder()** Get the grid ordering, either "yx" if latitude is the first axis, or "xy" if longitude is the first axis.

Table 2.27 RectGrid Methods

Type	Definition
String	**getType()** Get the grid type, either “gaussian”, “uniform”, “equalarea”, or “generic”.

(Array,Array)	**getWeights()**
	Get the normalized area weight arrays, as a tuple (latWeights, lonWeights). It is assumed that the latitude and longitude axes are defined in degrees.
	The latitude weights are defined as:
	`latWeights[i] = 0.5 * abs(sin(latBounds[i+1]) - sin(latBounds[i]))`
	The longitude weights are defined as:
	`lonWeights[i] = abs(lonBounds[i+1] - lonBounds[i])/360.0`
	For a global grid, the weight arrays are normalized such that the sum of the weights is 1.0
	Example: Generate the 2-D weights array, such that weights[i.j] is the fractional area of grid zone [i,j].
	`import Numeric`
	`latwts, lonwts = grid.getWeights()`
	`weights = latwts[:,Numeric.NewAxis]*lonwts`

Table 2.27 RectGrid Methods

Type	Definition
None	**setBounds(latBounds, lonBounds, persistent=0)** Set the grid boundaries. *latBounds* is a NumPy array of shape (n,2), such that the boundaries of the kth axis value are [*latBounds*[k,0],*latBounds*[k,1]]. *lonBounds* is defined similarly for the longitude array. Note: By default, the boundaries are not written to the file or dataset containing the grid (if any). This allows bounds to be set on read-only files, for regridding. If the optional argument *persistent* is set to 1, the boundary array is written to the file.
None	**setMask(mask, persistent=0)** Set the grid mask. If persistent==1, the mask values are written to the associated file, if any. Otherwise, the mask is associated with the grid, but no I/O is generated. *mask* is a two-dimensional, Boolean-valued Numeric array, having the same shape as the grid.
None	**setType(gridtype)** Set the grid type. *gridtype* is one of “gaussian”, “uniform”, “equalarea”, or “generic”.

Table 2.27 RectGrid Methods

Type	Definition
RectGrid	**subGrid((latStart,latStop),(lonStart,lonStop))** Create a new grid, with latitude index range [latStart : latStop] and longitude index range [lonStart : lonStop]. Either index range can also be specified as None, indicating that the entire range of the latitude or longitude is used. For example, `newgrid = oldgrid.subGrid(None, (lonStart, lonStop))` creates **`newgrid`** corresponding to all latitudes, and index range [lonStart:lonStop] of **`oldgrid`**. If a mask is defined, the subgrid also has a mask corresponding to the index ranges. Note: The result grid is not associated with any file or dataset.

Table 2.27 RectGrid Methods

Type	Definition
RectGrid	**subGridRegion(latInterval, lonInterval)** Create a new grid corresponding to the coordinate region defined by latInterval, lonInterval. *latInterval* and *lonInterval* are the coordinate intervals for latitude and longitude, respectively. Each interval is a tuple having one of the forms: (x,y) (x,y,indicator) (x,y,indicator,cycle) None where *x* and *y* are coordinates indicating the interval [x,y), and: *indicator* is a two-character string, where the first character is 'c' if the interval is closed on the left, 'o' if open, and the second character has the same meaning for the right-hand point. (Default: ‘co’) If *cycle* is specified, the axis is treated as circular with the given cycle value. By default, if grid.isCircular() is true, the axis is treated as circular with a default value of 360.0. An interval of None returns the full index interval of the axis. If a mask is defined, the subgrid also has a mask corresponding to the index ranges. Note: The result grid is not associated with any file or dataset.

Table 2.27 RectGrid Methods

Type	Definition
RectGrid	**transpose()** Create a new grid, with axis order reversed. The grid mask is also transposed. Note: The result grid is not associated with any file or dataset.

2.10 Variable

A Variable is a multidimensional data object. The domain of a variable is defined in terms of Axis and Grid objects.

A Variable is contained in a Dataset. Setting a slice of a Variable writes data to the Dataset, and referencing a Variable slice reads data from the Dataset.

Table 2.28 Variable Internal Attributes

Type	Name	Definition
Dictionary	attributes	External attribute dictionary.
List	domain	Axes contained in the dataset. Each element of the list is itself a tuple of the form `(axis,start,length,true_length)` where *axis* is an axis object, *start* is the start index of the domain relative to the axis object, *length* is the length of the axis, and *true_length* is the actual number of (defined) points in the domain
String	id	Variable identifier.
String	name_in_file	The name of the variable in the file or files which represent the dataset. If different from **id**, the variable is ‘aliased’.

Table 2.28 Variable Internal Attributes

Type	Name	Definition
Dataset or CdmsFile	parent	The dataset or file which contains the variable.
Tuple	shape	The length of each axis of the variable.

Table 2.29 Variable Constructors

Dataset.createVariable(String id, String datatype, List axes)

Create a Variable in a Dataset. **This function is not yet implemented.**

CdmsFile.createVariable(String id, String datatype, List axesOrGrids)

Create a Variable in a CdmsFile.

id is the name of the variable.

datatype is a CDMS datatype, as defined in Table 2.13 on page 36..

axesOrGrids is a list of Axis and/or Grid objects, on which the variable is defined. Specifying a rectilinear grid is equivalent to listing the grid latitude and longitude axes, in the order defined for the grid. Note: this argument can either be a list or a tuple. If the tuple form is used, and there is only one element, it must have a following comma, e.g.: (axisobj,).

Table 2.30 Variable Methods

Type	Definition
Array	**array = var[i:j, m:n]** Read a slice of data from the external dataset. Data is returned in the physical ordering defined in the dataset. The forms of the slice operator are listed in Table 2.31 on page 63. Note: enabling autoReshape mode causes singleton dimensions to be removed from the result array. (See **cdms.setAutoReshapeMode**.) By default, this mode is off. **var[i:j, m:n] = array** Write a slice of data to the external dataset. The forms of the slice operator are listed in Table 2.21 on page 32. (Variables in CdmsFiles only)
None	**assignValue(Array ar)** Write the entire data array. Equivalent to var[:] = ar. (Variables in CdmsFiles only).
Axis	**getAxis(n)** Get the n-th axis. *n* is an integer.
Grid	**getGrid()** Return the associated grid, or None if the variable is not gridded.
Axis	**getLatitude()** Get the latitude axis, or None if not found.
Axis	**getLevel()** Get the vertical level axis, or None if not found.

Table 2.30 Variable Methods

Type	Definition
Axis	**getLongitude()** Get the longitude axis, or None if not found.
Various	**getMissing()** Get the missing data value, or None if not found.
String	**getOrder()** Get the order string of a spatio-temporal variable. The order string specifies the physical ordering of the data. It is a string of characters with length equal to the rank of the variable, indicating the order of the variable's time, level, latitude, and/or longitude axes. Each character is one of: 't': time 'z': vertical level 'y: latitude 'x': longitude '-': the axis is not spatio-temporal. **Example**: A variable with ordering "tzyx" is 4-dimensional, where the ordering of axes is (time, level, latitude, longitude). Note: The order string is of the form required for the *order* argument of a regridder function.
List	**getPaths(*intervals)** Get the file paths associated with the index region specified by intervals. *intervals* is a list of scalars, 2-tuples representing [i,j), slices, and/or Ellipses. If no argument(s) are present, all file paths associated with the variable are returned. Returns a list of tuples of the form (path,slicetuple), where *path* is the path of a file, and *slicetuple* is itself a tuple of slices, of the same length as the rank of the variable, representing the portion of the variable in the file corresponding to *intervals*.

Table 2.30 Variable Methods

Type	Definition
Array	**getRegion(*region)** Read a region of data. A region is a hyperrectangle in coordinate space. *region* is an argument list, each item of which specifies an interval of a coordinate axis. The intervals are listed in the order of the variable axes. If trailing dimensions are omitted, all values of those dimensions are retrieved. If an axis is circular (**axis.isCircular()** is true) or cycle is specified (see below), then data will be read with wraparound in that dimension. Only one axis may be read with wraparound. A coordinate interval has one of the forms listed in Table 2.32 on page 64. Also see **cdms.setAutoReshapeMode**. See examples below.
String	**getTemplate()** Get the file template associated with this variable. If no template is associated with the variable, the dataset template is returned.
Axis	**getTime()** Get the time axis, or None if not found.
Array	**getValue()** Read the entire array. Equivalent to a = var[:]
Integer	**len(var)** The length of the first dimension of the variable. If the variable is zero-dimensional (scalar), a length of 0 is returned.
String	**typecode()** The Numeric datatype identifier.

Example: Get a region of data.

Variable ta is a function of (time, latitude, longitude). Read data corresponding to all times, latitudes -45.0 up to but not including +45.0, longitudes 0.0 through and including longitude 180.0:

```
data = ta.getRegion(':', (-45.0,45.0), (0.0, 180.0, 'cc'))
```

In the previous example, assume that times are represented as relative times with units "days since 1979-01-01". Read all data for 1980:

```
import cdtime

# Convert absolute times 1980-01-01, 1981-01-01 to
# relative times with the correct units.

t80 = cdtime.comptime(1980).torel("days since 1979")
t81 = cdtime.comptime(1981).torel("days since 1979")

# Read the data for 1980. The interval represents all
# times t such that t80 <= t < t81. Also note that
# intervals for the trailing dimensions latitude
# and time can be omitted.

data = ta.getRegion((t80.value,t81.value))
```

Table 2.31 Variable Slice Operators

[i]	The ith element, zero-origin indexing.
[i:j]	The ith element through, but not including, element j
[i:]	The ith element through the end
[:j]	The beginning element through, but not including, element j
[:]	The entire array
[i:j:k]	Every kth element
[i:j, m:n]	Multidimensional slice
[i, ..., m]	(Ellipsis) All values of all dimensions between the first and last
[-1]	Negative indices 'wrap around'. -1 is the last element.

Table 2.32 Coordinate Intervals used in getRegion()

Interval	Definition	Example
x	single point, such that axis[i]==x	180.0
(x,y)	indices i such that x <= axis[i] < y	(-180,180)
(x,y,'cc')	x <= axis[i] <= y The third item is defined as in mapInterval.	(-90,90,'cc')
(x,y,'co',cycle)	x<= axis[i] < y, with wraparound Note: It is not necesary to specify the cycle of a circular longitude axis, that is, for which axis.isCircular() is true.	(-180,180,'co',360.0)
':' or None	all axis values of one dimension	
Ellipsis	all values of all intermediate axes	

2.11 Examples

In this example, two datasets are opened, containing surface air temperature (‘tas’) and upper-air temperature (‘ta’) respectively. Surface air temperature is a function of (time, latitude, longitude). Upper-air temperature is a function of (time, level, latitude, longitude). Time is assumed to have a relative representation in the datasets (e.g., with units “months since basetime”).

Data is extracted from both datasets for January of the first input year through December of the second input year. For each time and level, three quantities are calculated: slope, variance, and correlation. The results are written to a netCDF file. For brevity, the functions corrCoefSlope and removeSeasonalCycle are omitted.

1

```
import cdms, Numeric
```

```
from cdtime import *

# Write slope, correlation, and variance variables
def writeNetCDF(lons,lats,levs,file_name,title,b,c,v):
    file = cdms.createDataset(file_name + '.nc')
    file.title = title
    lon_var = file.createAxis('longitude', lons)
    lon_var.units = "degrees_east"
    lat_var = file.createAxis('latitude', lats)
    lat_var.units = "degrees_north"
    lev_var = file.createAxis('level',levs)
    lev_var.units = 'mb'

    foo = file.createVariable('slope', cdms.CdDouble, (lev_var, lat_var,
        lon_var))
    foo[:] = b
    foo = file.createVariable('correlation', cdms.CdDouble, (lev_var, lat_var,
        lon_var))
    foo[:] = c
    foo = file.createVariable('variance', cdms.CdDouble, (lev_var, lat_var,
        lon_var))
    foo[:] = v
    file.close()

def mapTimes(year1, year2, units, calendar):
    time1 = comptime(year1,1).torel(units,calendar).value
    time2 = comptime(year2,12).torel(units,calendar).value
    return time1,time2

# Calculate variance, slope, and correlation of surface air tempature
# with upper air temperature
# by level, and save to a netCDF file. 'pathTa' is the location of
# the CDMS dataset containing ta, 'pathTas' is the file with contains tas.
# Data is extracted from January of year1 through December of year2.
def ccSlopeVarianceBySeasonFiltNet(pathTa,pathTas,year1,year2):

    # Open the files for ta and tas

    fta  = cdms.openDataset(pathTa)
    ftas = cdms.openDataset(pathTas)

    # Get upper air temperature and axes

    taObj = fta.variables['ta']
    levs  = taObj.getLevel()[:]
    lats  = taObj.getLatitude()[:]
    lons  = taObj.getLongitude()[:]

    # Surface temperature times
    timeObj = ftas.axes['time']
    calendar = timeObj.getCalendar()
    if calendar==None: calendar=NoLeapCalendar

    # Get the timepoints corresponding to January of year1,
    # and December of year2.
    time1, time2 = mapTimes(year1,year2,timeObj.units,calendar)

    # Get the surface temperature for the closed interval [time1,time2]
    i1,i2 = timeObj.mapInterval((time1,time2),'cc')
    tas = ftas.variables['tas'][i1:i2]

    # assert time_bounds[0] == 1 and time_bounds[1] == 12
```

```
    cc = Numeric.zeros( (len(levs),tas.shape[1],tas.shape[2]), Numeric.Float)
    b = Numeric.zeros( (len(levs),tas.shape[1],tas.shape[2]), Numeric.Float)
    v = Numeric.zeros( (len(levs),tas.shape[1],tas.shape[2]), Numeric.Float)

    # Remove seasonal cycle from surface air temperature
    tas = removeSeasonalCycle(tas)

    # Get correct indices for ta
    timeObj = fta.axes['time']
    calendar = timeObj.getCalendar()
    if calendar==None: calendar=cdtime.NoLeapCalendar
    time1, time2 = mapTimes(year1,year2,timeObj.units,calendar)
    i1,i2 = timeObj.mapInterval((time1,time2),'cc')

    # For each level of air temperature, remove seasonal cycle
    # from upper air temperature, and calculate statistics
    for ilev in range(len(levs)):
        print 'level = ',ilev, levs[ilev]
(8)     ta = taObj[i1:i2,ilev]
        ta.shape = tas.shape # Ensure that the arrays conform
        ta = removeSeasonalCycle(ta)
        cc[ilev], b[ilev]  = corrCoefSlope(tas ,ta)
        v[ilev] = Numeric.add.reduce( ta**2 )/(1.0*ta.shape[0])
    file_name = 'CC_B_V_ALL'
    title = 'filtered'
    writeNetCDF(lons,lats,levs,file_name,title,b,cc,v)

(9) if __name__=='__main__':
    pathTa = '/pcmdi/cdms/sample/ccmSample_ta.xml'
    pathTas = '/pcmdi/cdms/sample/ccmSample_tas.xml'
    # Process Jan80 through Dec81
    ccSlopeVarianceBySeasonFiltNet(pathTa,pathTas,1980,1981)
```

Notes:

1. Three modules are imported, **cdms**, **Numeric**, and **cdtime**. **Numeric** implements array functions. **cdtime** supports time arithmetic.
2. The writeNetCDF function creates a new netCDF file, and writes three variables to the file: **`b`** (slope), **`c`** (correlation), and **`v`** (variance). **`lons`**, **`lats`**, and **`levs`** are 1-D arrays for longitude, latitude, and level axes, respectively.

   The file is created with the **createDataset** function. Since the file extension is not **`.xml`** or **`.cdml`**, a CdmsFile is created.

   Setting **`file.title`** creates and sets a global attribute in the file.

   Three axes are created via **createAxis**, and the units attributes are set.

   The three variables are created via **createVariable**. The domain is specified as a list of axis objects created previously.

The line **`foo[:] = b`** writes the array b to variable foo in the file.

It is important to close the file, to ensure that all data is written.

3. **`mapTimes`** returns a tuple of relative time values (**`time1`**, **`time2`**), where:
   - **`time1`** is January of **`year1`**, and
   - **`time2`** is December of **`year2`**.
   comptime is a **cdtime** function which creates a component time. **torel**() translates to the appropriate relative units.
4. The two datasets are opened via **openDataset**(). **`fta`** is the dataset containing upper-air temperature, and **`ftas`** is the dataset containing surface air temperature.
5. The variable **`taObj`** is retrieved using the predefined dataset attribute **`.variables`**. This is a dictionary with the variable ids as keys.

   getLevel() returns the level (vertical dimension) axis for **`ta`**. The slice operator [:] reads the entire array, so that **`levs`** is a Numeric array containing the levels. The same is true of latitude and longitude.
6. Datasets have a **`.axes`** attribute, which is a dictionary of all Axes in the file. It is assumed that the time axis has id **`'time'`**, so **`timeObj`** is the time axis. A better approach is to use the **getTime**() function to retrieve the time axis.

   `calendar` is the **cdtime** calendar associated with the time axis. If no calendar is specified in the dataset, it is assumed to be the Gregorian calendar.
7. The **mapInterval** function maps the coordinate interval (**`time1, time2`**) to an index interval. The optional **`'cc'`** indicator specifies that the interval is closed on both ends, that is , **`time1`** and **`time2`** are both contained in the interval. If the indicator were omitted, it would default to **`'co'`**, meaning closed on the left, open on the right.

   mapInterval returns indices **`(i1,i2)`**, which represents all integers k such that i1<=k<i2. In other words, the closed coordinate interval **`(time1,time2,'cc')`** maps to the half-open index interval **`(i1,i2)`**.

   This could also have been accomplished more directly using the **getRegion**() function, which takes an argument list of coordinate intervals. The following obtains the same result:

```
tasObj = ftas.variables['tas']
tas = tasObj.getRegion((time1,time2,'cc'))
```

8. **ta** is read using a multidimensional slice operator. Since **ta** is assumed to be a function of (time, level, latitude, longitude), the operation
   ta = taObj[i1:i2,ilev]
   reads times with indices **i1** through **i2-1**, level **ilev**, all latitudes, all longitudes.
9. This is the main routine of the script. **pathTa** and **pathTas** are dataset paths which reference the XML metafiles. Data is processed from January 1980 through December 1981.

In the next example, the pointwise variance of a variable over time is calculated, for all times in a dataset. The name of the dataset is input, all variables in the dataset are printed, then the name of the variables is selected. The variance is then calculated and plotted via the vcs module.

```
#!/pcmdi/drach/cdat/python15/python
#
# Calculates gridpoint total variance
# from an array of interest
#

from Numeric import *
import cdms

AxisNotTime = 'First axis is not time, variable:'

# Create a netCDF file, write v(lon,lat)
def writenc(filename,lons,lats,v):
    f = cdms.createDataset('calcVar.nc')
    lon = f.createAxis('longitude',lons)
    lat = f.createAxis('latitude',lats)
    varvar = f.createVariable('variance', cdms.CdDouble, (lat,lon))
    varvar[:] = v
    f.close()

# Generate a plot of a 2-D array 'ar'.
# 'w' is the VCS window object returned from vcs.init()
# 'xar' and 'yar' are the x-axis and y-axis coordinates.
# 'aname', 'xname', and 'yname' are the names of the array, x-axis, and y-axis.
# 'xbounds' and 'ybounds' are boundary arrays.
10  def plot2d (w,ar,xar,yar,aname,xname,yname,units=None,
          xbounds=None,ybounds=None):
    if xbounds is None:
       xbounds = [1.5*xar[0]-0.5*xar[1]] + ((xar[0:-1]+xar[1:])/2.0).tolist() +
         [1.5*xar[-1]-0.5*xar[-2]]
    if ybounds is None:
       ybounds = [1.5*yar[0]-0.5*yar[1]] + ((yar[0:-1]+yar[1:])/2.0).tolist() +
         [1.5*yar[-1]-0.5*yar[-2]]
    ar.setdimattribute(0,'values',yar.tolist())
    ar.setdimattribute(1,'values',xar.tolist())
    ar.setdimattribute(0,'bounds',ybounds)
    ar.setdimattribute(1,'bounds',xbounds)
    ar.setdimattribute(0,'name',yname)
    ar.setdimattribute(1,'name',xname)
```

```
    if units is not None:
        ar.createattribute('units')
        ar.setattribute('units',units)
    ar.setattribute('name',aname)
    w.plot(ar,'AMIP')

# Wait for return in an interactive window
def pause():
    print 'Hit return to continue: ',
    line = sys.stdin.readline()

# Calculate pointwise variance of variable over time
# Returns the variance and the number of points
# for which the data is defined, for each grid point

def calcVar(var):
    # Check that the first axis is a time axis
11  firstaxis = var.domain[0][0]
    if not firstaxis.isTime():
        raise AxisNotTime, var.id

    # Read the entire variable
    x = var[:]

    n = 1.*avg.count(x)
    sumxx = addmissing.reduce(x*x)
    sumx = addmissing.reduce(x)
    variance = (n*sumxx - (sumx * sumx))/(n * (n-1.))

    return variance,n

if __name__=='__main__':
    import vcs, sys

    print 'Enter dataset path [/pcmdi/cdms/sample/obs/erbs_mo.xml]: ',
    path = string.strip(sys.stdin.readline())
    if path=='': path='/pcmdi/cdms/sample/obs/erbs_mo.xml'

    # Open the dataset
12  dataset = cdms.openDataset(path)

    # Select a variable from the dataset
    print 'Variables in file:',path
    varnames = dataset.variables.keys()
    varnames.sort()
    for varname in varnames:
        var = dataset.variables[varname]
        if hasattr(var,'long_name'):
            long_name = var.long_name
        elif hasattr(var,'title'):
            long_name = var.title
        else:
            long_name = '?'
        print '%-10s: %s'%(varname,long_name)
    print 'Select a variable: ',
    varname = string.strip(sys.stdin.readline())
    var = dataset.variables[varname]

    # Calculate variance
    variance,n = calcVar(var)
    dataset.close()
```

```
    # Get longitude and latitude arrays
    x = var.getLongitude()[:]
13  y = var.getLatitude()[:]

    # Save the data
    writenc('calcVar.nc',x,y,variance)

    # Plot variance
    w=vcs.init()
    w.setcolormap('default')
    if hasattr(var,'units'):
        units = var.units
    else:
        units = None
14  plot2d(w,variance,x,y,varname+'
         variance','longitude','latitude','(%s)^2'%units)
    pause()
    w.clear()
    plot2d(w,n,x,y,varname+' npts defined','longitude','latitude')
    pause()
    w.clear()
```

The result of running this script is as follows:

```
% calcVar.py
Enter dataset path [/pcmdi/cdms/sample/obs/erbs_mo.xml]:
 Variables in file: /pcmdi/cdms/sample/obs/erbs_mo.xml
albt      : Albedo TOA [%]
albtcs    : Albedo TOA clear sky [%]
rlcrft    : LW Cloud Radiation Forcing TOA [W/m^2]
rlut      : LW radiation TOA (OLR) [W/m^2]
rlutcs    : LW radiation upward TOA clear sky [W/m^2]
rscrft    : SW Cloud Radiation Forcing TOA [W/m^2]
rsdt      : SW radiation downward TOA [W/m^2]
rsut      : SW radiation upward TOA [W/m^2]
rsutcs    : SW radiation upward TOA clear sky [W/m^2]
Select a variable: albt

<The variance is plotted>

Hit return to continue:

<The number of points is plotted>
```

Notes:

10. The plot2d function creates a boxfill plot of the 2-D array **`ar`** in window **`w`**. The setdimattribute and setattribute functions are PCMDI Numeric extensions.

11. The domain of a variable is a list [elem1, elem2, ..., elemn] where each element is a tuple of the form (axis,start,length,true_length). In this example, **`var.domain[0]`** is the domain element for the first axis, and **`var.domain[0][0]`** is the first axis object.

12. The dataset is opened via **openDataset**().

13. **`var.getLongitude()`** gets the longitude axis. The slice operator [:] reads the associated array.
14. The variance is plotted first, then the number of defined points is plotted.

CHAPTER 3

Regridding data

3.1 Overview

This chapter describes how to interpolate gridded CDMS data to another horizontal grid, within Python.

Regridding data is a two-step process:

- Given an input grid and output grid, generate a regridder function.
- Call the regridder function on a Numeric array, resulting in an array defined on the output grid.

The following example illustrates this process. The regridder function is generated at line 9, and the regridding is performed at line 10:

```
 1  #!/usr/local/bin/python
 2  import cdms
 3  from regrid import Regridder
 4  f = cdms.openDataset('/pcmdi/cdms/exp/cmip2/ccc/perturb.xml')
 5  rlsf = f.variables['rls']
 6  ingrid = rlsf.getGrid()
 7  g = cdms.openDataset('/pcmdi/cdms/exp/cmip2/mri/perturb.xml')
 8  outgrid = g.variables['rls'].getGrid()
 9  regridfunc = Regridder(ingrid, outgrid)
10  rlsnew = regridfunc(rlsf[:])
```

```
11  f.close()
12  g.close()
```

Line	Notes
2	Makes the CDMS module available.
3	Makes the **`Regridder`** class available from the **`regrid`** module.
4	Opens the input dataset.
5	Gets the variable object named **`'rls'`**. No data is read.
6	Gets the input grid.
7	Opens a dataset to retrieve the output grid.
8	The output grid is the grid associated with the variable named **`'rls'`** in dataset **`g`**. Just the grid is retrieved, not the data.
9	Generates a regridder function **`regridfunc`**.
10	Reads all data for variable **`rlsf`**, and calls the regridder function on that data, resulting in a Numeric array **`rlsnew`**.

3.2 regrid module

The regrid module implements the regridding functionality. Although this module is not strictly a part of CDMS, it is designed to work with CDMS objects. The Python command

```
from regrid import Regridder
```

makes the Regridder class available within a Python program. An instance of Regridder is a function which regrids data from input to output grid.

Table 3.1 Regridder Constructor

regridFunction = Regridder(inputGrid, outputGrid) Create a regridder function which interpolates a data array from input to output grid. Table 3.2 on page 77 describes the calling sequence of this function. *inputGrid* and *outputGrid* are CDMS grid objects. Note: To set the mask associated with *inputGrid* or *outputGrid*, use the grid **setMask** function.

3.3 regridder functions

A regridder function is an instance of the Regridder class. The function is associated with an input and output grid. Typically its use is straightforward: the function is passed an input array and returns the regridded array. However, when the array has missing data, or the input and/or output grids are masked, the logic becomes more complicated.

Step 1: The regridder function first forms an *input mask*. This mask is either two-dimensional or 'n-dimensional', depending on the rank of the user-supplied mask.

Two-dimensional case:

- Let *mask_1* be the two-dimensional user mask supplied via the **`mask`** argument, or the mask of the input grid if no user mask is specified.
- If a missing-data value is specified via the **`missing`** argument, let the *implicit_mask* be the two-dimensional mask defined as 0 where the first horizontal slice of the input array is missing, 1 elsewhere.
- The input mask is the logical AND(*mask_1*, *implicit_mask*)

N-dimensional case: If the user mask is 3 or 4-dimensional with the same shape as the input array, it is used as the input mask.

Step 2: The data is then regridded. In the two-dimensional case, the input mask is ‘broadcast’ across the other dimensions of the array. In other words, it assumes that all horizontal slices of the array have the same mask. The result is a new array, defined on the output grid. Optionally, the regridder function can also return an array having the same shape as the output array, defining the fractional area of the output array which overlaps a non-missing input grid cell. This is useful for calculating area-weighted means of masked data.

Step 3: Finally, if the output grid has a mask, it is applied to the result array. Where the output mask is 0, data values are set to the missing data value, or 1.0e20 if undefined.

Table 3.2 Regridder function

Type	
Array	***regridFunction*(array, missing=None, order=None, mask=None)** Interpolate a gridded data array to a new grid. The interpolation preserves the area-weighted mean on each horizontal slice. An array of the same rank as the input array is returned. *array* is a Numeric array of rank 2, 3, or 4. *missing* is a Float specifying the missing data value. The default is 1.0e20. *order* is a string indicating the order of dimensions of the array. It has the form returned from **variable.getOrder()**. For example, the string "tzyx" indicates that the dimension order of *array* is (time, level, latitude, longitude). If unspecified, the function assumes that the last two dimensions of *array* match the input grid. *mask* is a Numeric array, of datatype Integer or Float, consisting of ones and zeros. A value of 0 or 0.0 indicates that the corresponding data value is to be ignored for purposes of regridding. If *mask* is two-dimensional of the same shape as the input grid, it overrides the mask of the input grid. If the mask has more than two dimensions, it must have the same shape as *array.* In this case, the *missing* data value is also ignored. Such an n-dimensional mask is useful if the pattern of missing data varies with level (e.g., ocean data) or time.
Array, Array	***regridFunction*(ar, missing=None, order=None, mask=None, returnTuple=1)** If called with the optional returnTuple argument equal to 1, the function returns a tuple (*dataArray, maskArray*). *dataArray* is the result data array. *maskArray* is a Float32 array of the same shape as *dataArray*, such that *maskArray*[i,j] is fraction of the output grid cell [i,j] overlapping a non-missing cell of the input grid.

3.4 Examples

Example: Create a uniform output grid.

```
 1  #!/usr/local/bin/python
 2  import cdms
 3  from regrid import Regridder
 4  f = cdms.openDataset('rls_ccc_per.nc')
 5  rlsf = f.variables['rls']
 6  ingrid = rlsf.getGrid()
 7  outgrid = cdms.createUniformGrid(90.0, 46, -4.0, 0.0, 72, 5.0)
 8  regridFunc = Regridder(ingrid, outgrid)
 9  newrls = regridFunc(rlsf[:], missing=rlsf.getMissing())
10  f.close()
```

Line	Notes
4	Open a netCDF file for input.
7	Create a 4 x 5 degree output grid. Note that this grid is not associated with a file or dataset
8	Create the regridder function
9	Read all data and regrid. The missing data flag is set explicitly.

Example: Get a mask from a separate file, and set as the input grid mask.

```
1  import cdms
2  from regrid import Regridder
3  cdms.setAutoReshapeMode('on')
4  f = cdms.openDataset('so_ccc_per.nc')
5  sof = f.variables['so']
6  ingrid = sof.getGrid()
```

```
 7  g = cdms.openDataset('rls_mri_per.nc')
 8  rlsg = g.variables['rls']
 9  outgrid = rlsg.getGrid()
10  regridFunc = Regridder(ingrid,outgrid)
11  h = cdms.openDataset('sft_ccc.nc')
12  sfth = h.variables['sft']
13  sftArray = sfth[:]
14  outArray =
    regridFunc(sof[:],missing=sof.getMissing(),mask=sftMask)
15  f.close()
16  g.close()
17  h.close()
```

Line	Notes
3	Enable autoreshape mode. This removes singleton dimensions when data is read from a file.
6	Get the input grid.
9	Get the output grid
10	Create the regridder function.
13	Get the mask.
14	Regrid with a user mask. The same thing could be accomplished by setting the mask of ingrid via the **setMask** method. Note: Although it cannot be determined from the code, both **`mask`** and the input array **`sof`** are four-dimensional. This is the 'n-dimensional' case.

Example: Generate an array of zonal mean values.

```
1  f = cdms.openDataset('rls_ccc_per.nc')
2  rlsf = f.variables['rls']
3  ingrid = rlsf.getGrid()
4  outgrid = cdms.createZonalGrid(ingrid)
5  regridFunc = Regridder(ingrid,outgrid)
```

```
6  mean = regridFunc(rlsf[:])
7  f.close()
```

Line	Notes
3	Get the input grid.
4	Create a zonal grid. **outgrid** has the same latitudes as **ingrid**, and a singleton longitude dimension. **createGlobalMeanGrid** could be used here to generate a global mean array.
5	Generate the regridder function.
6	Generate the zonal mean array.

Example: Regrid an array with missing data, and calculate the area-weighted mean of the result.

```
1  from Numeric import *
   ...
2  outgrid = cdms.createUniformGrid(90.0, 46, -4.0, 0.0, 72, 5.0)
3  outlatw, outlonw = outgrid.getWeights()
4  outweights = outlatw[:,NewAxis]*outlonw
5  grid = var.getGrid()
6  sample = var[0,0]
7  latw, lonw = grid.getWeights()
8  weights = latw[:,NewAxis]*lonw
9  inmask = where(greater(absolute(sample),1.e15),0,1)
10 mean = add.reduce(ravel(inmask*weights*sample))/
   add.reduce(ravel(inmask*weights))
11 regridFunc = Regridder(grid, outgrid)
12 outsample, outmask = regridFunc(sample, mask=inmask,
   returnTuple=1)
13 outmean = add.reduce(ravel(outmask*outweights*outsample))/
   add.reduce(ravel(outmask*outweights))
```

Line	Notes
2	Create a uniform target grid.
3	Get the latitude and longitude weights.
4	Generate a 2-D weights array.
5	Get the input grid. **`var`** is a 4-D variable.
6	Get the first horizontal slice from **`var`**.
7-8	Get the input weights, and generate a 2-D weights array.
9	Set the 2-D input mask.
10	Calculate the input array area-weighted mean.
11	Create the regridder function.
12	Regrid. Because **`returnTuple`** is set to 1, the result is a tuple (dataArray, maskArray).
13	Calculate the area-weighted mean of the regridded data. **`mean`** and **`outmean`** should be approximately equal.

CHAPTER 4

Plotting CDMS data in Python

4.1 Overview

Data read via the CDMS Python interface can be plotted using the **vcs** module. This module, part of the Climate Data Analysis Tool (CDAT) is documented in the CDAT reference manual. The **vcs** module provides access to the functionality of the VCS visualization program.

Examples of plotting data accessed from CDMS are given below, as well as documentation for the **plot** routine keywords.

4.2 Examples

In the following examples, it is assumed that variable `psl` is dimensioned (time, latitude, longitude). `psl` is contained in the dataset named `'sample.xml'`.

4.2.1 Example: plotting a horizontal grid

```
1  import cdms, vcs
2  cdms.setAutoReshapeMode('on')
```

```
3  f = cdms.openDataset('sample.xml')
4  psl = f.variables['psl']
5  sample = pr[0]
6  w=vcs.init()
7  w.setcolormap('default')
8  w.plot(sample, variable=psl)
9  f.close()
```

Notes:

Line	Notes
2	Remove singleton dimensions when data is read.
5	Get a horizontal slice, for the first timepoint.
6	Create a VCS Canvas `w`.
7	Set the default colormap.
8	Plot the data. By default, a boxfill plot of a horizontal lat-lon array is generated. The variable `psl` encapsulates information on the grid coordinates, variable name, units, etc.
9	Close the file. This must be done after the reference to the persistent variable `psl`.

That's it! The axis coordinates, variable name, description, units, etc. are obtained from variable `psl`.

What if the units are not explicitly defined for `psl`, or a different description is desired? **plot** has a number of other keywords.

4.2.2 Example: using plot keywords.

```
w.plot(sample, variable=psl, units='mm/day', file_comment='High-
    frequency reanalysis', long_name="Sea level pressure",
    comment1="Sample plot", hms="18:00:00", ymd="1978/01/01")
```

Notes:

- Keyword arguments can be listed in any order.
- Specific keywords take precedence over general keywords. In this example, the units **'mm/day'** takes precedence over **psl.units**.

4.2.3 Example: plotting a time-latitude slice

If the data to be plotted is not a lat-lon slice, the xaxis and yaxis keywords are used to specify the axes:

```
   ...
1  samp = psl[:,:,0]
2  lat = psl.getLatitude()
3  time = psl.getTime()
4  w = vcs.init()
5  w.plot(samp, name='psl', xaxis=lat, yaxis=time)
```

Notes:

Line	Notes
1	**samp** consists of all times, latitudes for longitude index 0
2	**lat** is the CDMS latitude axis object, not just the array. The **xarray**/**yarray** keywords can be used to specify a 1-D Numeric vector of values, as an alternative. The advantage of using **xaxis** and **yaxis** is that the **plot** routine can recognize the spatial orientation of the axes.
5	The **variable** keyword was not used here, so the **name** keyword defines the identifier.

4.2.4 Example: plotting subsetted data

It is important to note that a data array read from CDMS does not carry spatial coordinate information or other metadata with it, with the exception of a missing data value. The array argument of **plot** is just Numeric array, which can be read from a file or generated by a Numeric operation. There may not be a persistent variable or axis associated with the data a priori.

In the following example, the data corresponds to a proper subset of the time axis. A new CDMS axis object is created, corresponding to the subset retrieved.

```
   ...
1  samp = psl[0:100,:,0]
2  lat = psl.getLatitude()
3  time = psl.getTime()
4  w = vcs.init()
5  w.plot(samp, name='psl', xaxis=lat, yaxis=time.subaxis(0,100))
```

Because the first 100 times are retrieved, **samp** does not correspond to the dataset time axis, which contains all the time values. The **subaxis** method creates a new axis object corresponding to the first 100 timepoints.

4.3 plot method

The **plot** method is documented in the CDAT Reference Manual. This section augments the documentation with a description of the optional keyword arguments.

The general form of the plot command is:

canvas.**plot(***array* [, *args*] [,*key=value* [, *key=value* [, ...]]]**)**

where:

- *canvas* is a VCS Canvas object, created with the **vcs.init** method.
- *array* is a Numeric array, having between two and five dimensions. The last dimensions of the array is termed the 'x' dimension, the next-to-last the 'y' dimension, then 'z', 't', and 'w'. For example, if the array is three-dimensional,

the axes are (z,y,x). If array is four-dimensional, the axes are (t,z,y,x), and so on. (Note that the ‘t’ dimension need have no connection with time; any spatial axis can be mapped to any plot dimension. For a graphics method which is two-dimensional, such as boxfill, the y-axis is plotted on the horizontal, and the x-axis on the vertical.

- *args* are optional positional arguments:

  args := *template_name, graphics_method, graphics_name*
  template_name: the name of the VCS template (e.g., ‘AMIP’)
  graphics_method : the VCS graphics method (‘boxfill’)
  graphics_name: the name of the specific graphics method (‘default’)

  See the CDAT Reference Manual and VCS Reference Manual for a detailed description of these arguments.

- *key=value, ...* are optional keyword/value pairs, listed in any order. These are defined in Table 4.1 on page 87.

Table 4.1 plot keywords

key	type	value
comment1	string	Comment plotted above file_comment
comment2	string	Comment plotted above comment1
comment3	string	Comment plotted above comment2
continents	0 or 1	if ==1, plot continental outlines (default: plot if xaxis is longitude, yaxis is latitude -or- xname is ’longitude’ and yname is ’latitude’
file_comment	string	Comment, defaults to variable.parent.comment)

Table 4.1 plot keywords

key	type	value
grid	CDMS grid object	Grid associated with the data. Defaults to variable.getGrid()
hms	string	Hour, minute, second
long_name	string	Descriptive variable name, defaults to variable.long_name.
missing_value	same type as array	Missing data value, defaults to variable.getMissing()
name	string	Variable name, defaults to variable.id
time	cdtime relative or absolute time	time associated with the data. Example: cdtime.reltime(30.0, “days since 1978-1-1”)
units	string	Data units. Defaults to variable.units
variable	CDMS variable object	Variable associated with the data. The variable grid must have the same shape as the data array.
xarray ([y|z|t|w]array)	1-D Numeric array	Array of coordinate values, having the same length as the corresponding dimension. Defaults to xaxis[:] (y|z|t|waxis[:])
xaxis ([y|z|t|w]axis)	CDMS axis object	Axis object. **xaxis** defaults to grid.getAxis(0), **yaxis** defaults to grid.getAxis(1)

Table 4.1 plot keywords

key	type	value
xbounds (ybounds)	2-D Numeric array	Boundary array of shape (n,2) where n is the axis length. Defaults to xaxis.getBounds(), or xaxis.genGenericBounds() if None, similarly for **ybounds**.
xname ([y|z|t|w]name)	string	Axis name. Defaults to xaxis.id ([y|z|t|w]axis.id)
xrev (yrev)	0 or 1	If **xrev** (**yrev**) is 1, reverse the direction of the x-axis (y-axis). Defaults to 0, with the following exceptions: • If the y-axis is latitude, and has decreasing values, yrev defaults to 1 • If the y-axis is a vertical level, and has increasing pressure levels, yrev defaults to 1.
xunits ([y|z|t|w]units)	string	Axis units. Defaults to xaxis.units ([y|z|t|w]axis.units).
xweights (yweights)	1-D Numeric array	Axis weights, a NumPy array of the same length as the dimension, used to calculate the area-weighted mean. This keyword is meaningful only if the data is a horizontal, lat-lon slice. Defaults to grid.getWeights().

CHAPTER 5

Climate Data Markup Language (CDML)

5.1 Introduction

The Climate Data Markup Language (CDML) is the markup language used to represent metadata in CDMS. CDML is based on the W3C XML standard (http://www.w3.org). This chapter defines the syntax of CDML. Read this section if you will be building or maintaining a CDMS database.

XML, the eXtensible Markup Language, makes it possible to define interoperable dialects of markup languages. The most recent version of HTML, the Web hypertext markup language, is an XML dialect. CDML is also an XML dialect, geared toward the representation of gridded climate datasets. XML provides rigor to the metadata representation, ensuring that applications can access it correctly. XML also deals with internationalization issues, and holds forth the promise that utilities for browsing, editing, and other common tasks will be available in the future.

CDML files have the file extension **.xml** or **.cdml**.

5.2 Elements

A CDML document consists of a nested collection of *elements*. An *element* is a description of the metadata associated with a CDMS object. The form of an element is:

```
<tag attribute-list> element-content </tag>

or

<tag attribute-list />
```

where

- `tag` is a string which defines the type of element
- `attribute-list` is a blank-separated list of attribute-value pairs, of the form:

  `attribute = "value"`
- `element-content` depends on the type of element. It is either a list of elements, or text which defines the element values. For example, the content of an axis element either is a list of axis values, or is a **linear** element. For datasets, the content is the blank-separated list of elements corresponding to the axes, grids, and variables contained in the dataset.

The CDML elements are:

Table 5.1 CDML Tags

Tag	Description
attr	Extra attribute
axis	Coordinate axis
domain	Axes on which a variable is defined
domElem	Element of a variable domain
linear	Linearly-spaced axis values

Table 5.1 CDML Tags

Tag	Description
rectGrid	Rectilinear Grid
variable	Variable

5.3 *Special Characters*

XML reserves certain characters for markup. If they appear as content, they must be encoded to avoid confusion with markup:

Table 5.2 Special Character Encodings

Character	Encoding
<	&lt
>	&gt
&	&amp
“	&quot
‘	&apos

For example, the comment

```
Certain “special characters”, such as <, >, and ‘, must
be encoded.
```

would appear in an attribute string as:

```
comment = “Certain &quotspecial characters&quot, such
as &lt, &gt, and &apos, must be encoded.”
```

5.4 Identifiers

In CDMS, all objects in a dataset have a unique string *identifier*. The **id** attribute holds the value of this identifier. If the variable, axis, or grid has a string name within a data file, then the **id** attribute ordinarily has this value. Alternatively, the name of the object in a data file can be stored in the **name_in_file** attribute, which can differ from the **id**. Datasets also have IDs, which can be used within a larger context (databases).

An identifer must start with an alphabetic character (upper or lower case), an underscore (_), or a colon (:). Characters after the first must be alphanumeric, an underscore, or colon. There is no restriction on the length of an identifier.

5.5 GDT Metadata Standard

The GDT metadata standard (http://www-pcmdi.llnl.gov/drach/GDT_convention.html) defines a set of conventions for usage of netCDF. This standard is supported by CDML. The document defines names and usage for metadata attributes.

5.6 CDML Syntax

The following notation is used in this section:

- `Courier font` is used for a syntax specification. **`Bold font`** highlights literals.
- `(R|S)` denotes ‘either R or S’.
- `R*` denotes ‘zero or more R’.
- `R+` denotes ‘one or more R’.

A CDML document consists of a prolog followed by a single dataset element.

1. `CDML-document ::=  prolog dataset-element`

The prolog defines the XML version, and the Document Type Definition (DTD), a formal specification of the document syntax. See http://www.w3.org/TR/1998/REC-xml-19980210 for a formal definition of XML Version 1.0.

2. `prolog ::=`
   `<?xml version="1.0"?>`
   `<!DOCTYPE dataset SYSTEM "http://www-pcmdi.llnl.gov/~drach/cdms/cdml.dtd">`

5.6.1 Dataset Element

A dataset element describes a single dataset. The content is a list of elements corresponding to the axes, grids, and variables contained in the dataset. Axis, variable, and grid elements can be listed in any order, and an element ID can be used before the element is actually defined.

3. `dataset-element ::=` **`<dataset`** `dataset-attributes` **`>`**
   `dataset-content` **`</dataset>`**
4. `dataset-content ::= (axis-element | grid-element | variable-element)* extra-attribute-element+`

Table 5.3 Dataset Attributes

Attribute	Required?	GDT?	Notes
appendices	N	Y	Version number
calendar	N	Y	Calendar used for encoding time axes. “gregorian” | “julian” | “noleap” | “360”
comment	N	Y	Additional dataset information
Conventions	Y	Y	The netCDF metadata standard. Example: “GDT 1.3”
directory	N	N	Root directory of the dataset
frequency	N	N	Temporal frequency
history	N	Y	Evolution of the data

Table 5.3 Dataset Attributes

Attribute	Required?	GDT?	Notes
id	Y	N	Dataset identifier
institution	N	Y	Who made or supplied the data
production	N	Y	How the data was produced
project	N	N	Project associated with the data Example: “CMIP 2”
template	N	N	File template, Section 1.3.1. Also see notes for the variable template.

5.6.2 Axis Element

An axis element describes a single coordinate axis. The content can be a blank-separated list of axis values or a linear element. A linear element is a representation of a linearly-spaced axis as (start, delta, length).

5. `axis-element ::= <axis axis-attributes> axis-content> </axis>`
6. `axis-content ::= (axis-values | linear-element) extra-attribute-element*`
7. `axis-values ::= [value*]`
8. `linear-element ::= <linear delta=”value” length=”Integer” start=”value”> </linear>`

Table 5.4 Axis Attributes

Attribute	Required?	GDT?	Notes
associate	N	Y	IDs of variables containing alternative sets of coordinates.
axis	N	Y	The spatial type of the axis: "T" - time "X" - longitude "Y" - latitude "Z" - vertical level "-" - not spatiotemporal
bounds	N	Y	ID of the boundary variable
comment	N	N	String comment
compress	N	Y	Dimensions which have been compressed by gathering
datatype	Y	N	Char, Short, Long, Float, Double, or String
expand	N	Y	Coordinates prior to contraction
id	Y	N	Axis identifier. Also the name of the axis in the underlying file(s), if **name_in_file** is undefined.
isvar	N	N	"true" | "false" "false" if the axis does not have coordinate values explicitly defined in the underlying file(s). Default: "true"
length	N	N	Number of axis values, including values for which no data is defined. Cf. **partition_length**.
long_name	N	Y	Long description of a physical quantity
modulo	N	Y	Arithmetic modulo of an axis with circular topology.

Table 5.4 Axis Attributes

Attribute	Required?	GDT?	Notes
name_in_file	N	N	Name of the axis in the underlying file(s). See id.
old_interval	N	Y	Typical spacing between two adjacent coordinates of the uncontracted axis
partition	N	N	Section 1.3.2
partition_length	N	N	Number of axis points for which data is actually defined. If data is missing for some values, this will be smaller than the **length**.
positive	N	Y	Direction of positive for a vertical axis
old_spacing	N	Y	Adjunct to **old_interval**.
			"uniform" | "variable" | "disjoint"
topology	N	Y	Axis topology.
			"circular" | "linear"
units	Y	Y	Units of a physical quantity
weights	N	N	Name of the weights array

5.6.3 Grid Element

A grid element describes a horizontal, latitude-longitude grid which is rectilinear in topology,

9. `grid-element ::= <rectGrid grid-attributes> extra-attribute-element* </rectGrid>`

Table 5.5 RectGrid Attributes

Attribute	Required?	GDT?	Notes
id	Y	N	Grid identifier
type	Y	N	Grid classification “gaussian” | “uniform” | “equalarea” | “generic” Default: “generic”
latitude	Y	N	Latitude axis name
longitude	Y	N	Longitude axis name
mask	N	N	Name of associated mask variable
order	Y	N	Grid ordering “yx” | “xy” Default: “yx”, axis order is latitude, longitude

5.6.4 Variable Element

A variable element describes a data variable. The domain of the variable is an ordered list of *domain elements* naming the axes on which the variable is defined. A domain element is a reference to an axis or grid in the dataset.

The **length** of a domain element is the number of axis points for which data can be retrieved. The **partition_length** is the number of points for which data is actually defined. If data is missing, this is less than the **length**.

10. `variable-element ::= <variable variable-attributes> variable-content </variable>`
11. `variable-content ::= variable-domain extra-attribute-element*`
12. `variable-domain ::= <domain> domain-element* </domain>`

13. domain-element ::= **<domElem name=”**axis-name**”**
start=”Integer**” length=”**Integer**”**
partition_length=”Integer**”/>**

Table 5.6 Variable Attributes

Attribute	Required?	GDT?	Notes
id	Y	N	Variable identifier. Also, the name of the variable in the underlying file(s), if **name_in_file** is undefined.
add_offset	N	Y	Additive offset for packing data. See **scale_factor**.
associate	N	Y	IDs of variables containing alternative sets of coordinates
axis	N	Y	Spatio-temporal dimensions. Ex: “TYX” for a variable with domain (time, latitude, longitude)
comments	N	N	Comment string
datatype	Y	N	Char, Short, Long, Float, Double, or String
grid_name	N	N	Id of the grid
grid_type	N	N	“gaussian” | “uniform” | “equalarea” | “generic”
long_name	N	Y	Long description of a physical quantity.
missing_value	N	Y	Value used for data that are unknown or missint.
name_in_file	N	N	Name of the variable in the underlying file(s). See id.
scale_factor	N	Y	Multiplicative factor for packing data. See **add_offset**.
subgrid	N	Y	Records how data values represent subgrid variation.

Table 5.6 Variable Attributes

Attribute	Required?	GDT?	Notes
template	N	N	Name of the file template to use for this variable. Overrides the dataset value. Section 1.3.1.
units	N	Y	Units of a physical quantity.
valid_max	N	Y	Largest valid value of a variable
valid_min	N	Y	Smallest valid value of a variable
valid_range	N	Y	Largest and smallest valid values of a variable

5.6.5 Attribute Element

Attributes which are not explicitly defined by the GDT convention are represented as extra attribute elements. Any dataset, axis, grid, or variable element can have an extra attribute as part of its content. This representation is also useful if the attribute value has non-blank whitespace characters (carriage returns, tabs, linefeeds) which are significant.

The datatype is one of: Char, Short, Long, Float, Double, or String.

14. `extra-attribute-element ::= <attr name=attribute-name datatype="attribute-datatype"> attribute-value </attr>`

5.7 A Sample CDML Document

Dataset ‘sample’ has two variables, and six axes.

Note:

- The file is indented for readability. This is not required; the added whitespace is ignored.

- The dataset template indicates that the dataset is partitioned by variable (%v), vertical level (%L) and time (%Y). For variable ‘va’, the dataset template is superseded by the variable’s template attribute.
- The extra attribute format has the value “GRADS”. This is equivalent to

  format = “GRADS”
- The time attributes are represented as linearly spaced. All other axes are represented as vectors of values.
- The axis ‘time_22152’ is named ‘time’ in the underlying data file(s).
- variable ‘hur’ is a function of (time, level, latitude, longitude), with shape (1, 1, 73, 144). Variable ‘va’ is a function of (time_22152, level_2, latitude, longitude), with shape (22152, 2, 73, 144).

```
<?xml version="1.0"?>
<!DOCTYPE dataset SYSTEM "http://www-pcmdi.llnl.gov/~drach/cdms/cdml.dtd">
<dataset
    template="%v/sample/%v.%L..%Y.ctl"
    id  ="sample"
    Conventions="GDT 1.3"
    directory="/pcmdi/obs/sample/"
    >
    <attr name="format" datatype="String">GRADS</attr>
    <axis
        id  ="time"
        length="1"
        units="hours since 1979-1-1 0:0"
        datatype="Double"
        partition = "[0 1]"
        partition_length = "1"
        >

        <linear
            delta="0.0"
            length="1"
            start="0.0"
            >
            </linear>
        </axis>
    <axis
        id  ="level"
        length="1"
        units="lev"
        partition = "[0 1]"
        partition_length = "1"
        datatype="Float"
        >
        [ 850.]
        </axis>
    <axis
        id  ="latitude"
        length="73"
        units="degrees"
        datatype="Float"
```

```
    >
    [-90.  -87.5 -85.  -82.5 -80.  -77.5 -75.  -72.5 -70.  -67.5 -65.  -62.5
    ...
    80.   82.5  85.   87.5  90. ]
    </axis>
<axis
    id  ="longitude"
    length="144"
    units="degrees"
    datatype="Float"
    >
    [   0.     2.5    5.     7.5   10.    12.5   15.    17.5   20.    22.5
    ...
    352.5  355.   357.5]
    </axis>
<variable
    id  ="hur"
    missing_value="1.00000002004e+20"
    datatype="Float"
    >
    <attr name="title" datatype="String">Relative humidity [%]</attr>
    <domain
        >
        <domElem length="1" start="0" name="time"/>
        <domElem length="1" start="0" name="level"/>
        <domElem length="73" start="0" name="latitude"/>
        <domElem length="144" start="0" name="longitude"/>
        </domain>
    </variable>
<axis
    axis="T"
    id  ="time_22152"
    partition="[    0  1460  1460  2924  2924  4384  4384  5844  5844  7304
    7304  8768  8768
    10228 10228 11688 11688 13148 13148 14612 14612 16072 16072 17532
    17532 18992 18992 20456 20456 21916 21916 22152]"
    units="hours since 1979-1-1 0:0"
    datatype="Double"
    length="22152"
    partition_length="22152"
    name_in_file="time"
    >

    <linear
        delta="6.0"
        length="22152"
        start="0.0"
        >
        </linear>
    </axis>
<axis
    axis="Z"
    id  ="level_2"
    partition="[0 1 1 2]"
    units="lev"
    datatype="Float"
    length="2"
    partition_length="2"
    name_in_file="level"
    >

    <linear
```

```
            delta="-650.0"
            length="2"
            start="850.0"
            >
            </linear>
        </axis>
    <variable
        template="uva/rnl_ecm/uva.%L.rnl_ecm.%Y.ctl"
        id  ="va"
        missing_value="1.00000002004e+20"
        datatype="Float"
        >
        <attr name="title" datatype="String">Northward wind [m/s]</attr>
        <domain
            >
            <domElem partition_length="22152" name="time_22152" length="22152"
        start="0"/>
            <domElem partition_length="2" name="level_2" length="2" start="0"/
        >
            <domElem name="latitude" length="73" start="0"/>
            <domElem name="longitude" length="144" start="0"/>
            </domain>
        </variable>
    </dataset>
```

CHAPTER 6

CDMS Utilities

6.1 cdimport: Importing datasets into CDMS

6.1.1 Overview

A dataset is a partitioned collection of files. To make a dataset accessible within CDMS, it must first be *imported* into the database. CDMS represents datasets as an ASCII metafile in the CDML markup language. The file contains all metadata, together with information describing how the dataset is partitioned into files. (Note: CDMS provides an interface to individual files as well. It is not necessary to import an individual file to access it.)

For CDMS applications to work correctly, it is important that the CDML metafile be correct. The **cdimport** utility generates a metafile from a collection of data files.

CDMS assumes that there is some regularity in how datasets are partitioned:

- A variable can be partitioned (split across files) in at most two dimensions. The partitioned dimension(s) must be either time or vertical level dimensions; variables may not be partitioned across longitude or latitude. Datasets can be parti-

tioned by variable as well. For example, one set of files might contain heat fluxes, while another set contains wind speeds.

- The file names must be describable with a file template (see “File Template” on page 11.)

Otherwise, there is considerable flexibility in how a dataset can be partitioned:

- Files can contain a single variable or all variables in the dataset.
- The time axis can have gaps. Time can be represented as relative or absolute.
- Horizontal grid boundary information and related information can be duplicated across files.
- Variables can be omitted.
- Variables can be on different grids.
- Files may be in any of the self-describing formats supported by CDMS, including netCDF, HDF, GrADS/GRIB, and DRS.

6.1.2 cdimport Syntax

The syntax of the cdimport command is:

cdimport [**-dghjmrsv**] [**-e** *vectorEpsilon*] [**-l** *levelName*] [**-n** *variableName*] [**-t** *timeName*] [**-u** *variableName*] [**-x** *xmlFile*] *directory template datasetId*

where:

- *directory* is the root directory of the dataset. *directory* may not contain template specifiers (see “Template Specifiers” on page 49.)
- *template* is the file template which specifies the dataset partitioning. It is a pathname, relative to the directory, containing template specifiers.
- *datasetId* is a string identifier for the dataset.

Table 6.1 cdimport command options

Option	Description
d	Save output after each variable is scanned. By default no output is written until all files have been scanned. This option is useful for debugging.
e	Specify equality of axes. By default, axes in different files are treated as equivalent if their respective values are identical. Occasionally files contain axes which should be treated as identical, but have slightly different values. *vectorEpsilon* is interpreted as follows: two axis vectors x and y are treated as 'equal' if and only if for each element a(n), b(n), abs(a(n)-b(n))<=abs(a(n)*vectorEpsilon). The default value is 0.0.
g	Allow gaps in extended, linear time dimensions (see -s option).
h	Print help.
j	Ingest levels as increasing. By default, if vertical level values are split across files, the axis values are assumed to be decreasing.
l	Name of the extended level dimension. By default, the extended level dimension must have the name 'level'.
m	Ingest times as decreasing. By default, if the time axis is split across files, the axis values are assumed to be increasing.
n	Skip a variable. This option may be used more than once.
r	Assert that the extended time dimension is absolute time. By default time is relative by default (See "Python types used in CDMS" on page 14.)

Table 6.1 cdimport command options

Option	Description
s	Assert that the extended time dimension is linear. This option is recommended if the extended time dimension is large and is known to be linear, as the script will run much more quickly and generate more concise output. By default, the time dimension is represented as a list of time values. This is cumbersome when the time dimension is linear and very large. Using this option generates a more concise representation as (start, delta, length). The delta is determined as the difference between the first two time values found when the files are scanned. An error is raised if the time axis is not in fact linear. If the time dimension has gaps, use -g.
t	Name of the extended time dimension. By default, the time dimension must have name 'time'.
u	Flag *variableName* as duplicated in all files. Variables which represent axis bounds, weights, and other associated variables, as specified by the GDT convention, are included by default. This option may be used more than once.
v	Print the status of the ingest.
x	Save output as an XML file. By default, output is written to standard output.

6.1.3 Examples

1. Ingest the six-hourly NCEP reanalysis data. Treat time as linear, with possible gaps in the time dimension. Skip variable 'rsut'. Set the dataset ID to 'ncep_reanalysis_6h'. Print the status of the script.

```
cdimport -g -v -n rsut -x ncep_reanalysis_6h.xml /pcmdi/obs/6h/
    %v/rnl_ncep/%v.rnl_ncep.%Y.ctl ncep_reanalysis_6h
```

2. Ingest the CMIP control dataset for the CCC model.

```
cdimport -v -x ccc_con.xml /pcmdi/yoda4/dease/cmip/ccc
    %v_ccc_con.nc ccc_con
```

6.1.4 File Formats

Data may be represented in a variety of self-describing binary file formats, including

- netCDF, the Unidata Network Common Data Format
- HDF, the NCSA Hierarchical Data Format
- GrADS/GRIB, WMO GRIB plus a GrADS control file (.ctl)
  The first non-comment line of the control file must be a **dset** specification.
- DRS, the PCMDI legacy format.

6.1.5 Debugging

Given the wide variety of ways that data can be represented (or misrepresented) in the aforementioned file formats, there are many ways that cdimport can fail. Often, an option is available which will allow the import to succeed.

The best way to track down an error is to use the verbose option (-v). This generates a great deal of useful status information. Here is an excerpt from the output of Example 1:

```
% cdimport -g -v -n rsut -x sample.xml /pcmdi/obs/6h/
        %v/rnl_ncep/%v.rnl_ncep.%Y.ctl ncep_reanalysis_6h
['/usr/local/bin/cdimport', '-g', '-v', '-n', 'rsut', '-x', 'junk.xml', '/
        pcmdi/obs/6h/', '%v/rnl_ncep/%v.rnl_ncep.%Y.ctl',
        'ncep_reanalysis_6h']
Looking for matching files (this may take a while...)
*** Generating dataset ncep_reanalysis_6h from directory /pcmdi/obs/6h/ ,
        template %v/rnl_ncep/%v.rnl_ncep.%Y.ctl ***
List of variables found (in filenames): ['hfls', 'hfss', 'pr', 'psl', 'rlds',
        'rlus', 'rlut', 'rsds', 'rsdt', 'rsus', 'rsut', 'tauuv', 'uvas']
List of timepoints found: [(1978-1-1 0:0:0.0, None), (1979-1-1 0:0:0.0, None),
        (1980-1-1 0:0:0.0, None), (1981-1-1 0:0:0.0, None), (1982-1-1 0:0:0.0,
        None), (1983-1-1 0:0:0.0, None), (1984-1-1 0:0:0.0, None), (1985-1-1
        0:0:0.0, None), (1986-1-1 0:0:0.0, None), (1987-1-1 0:0:0.0, None),
        (1988-1-1 0:0:0.0, None), (1989-1-1 0:0:0.0, None), (1990-1-1 0:0:0.0,
        None), (1991-1-1 0:0:0.0, None), (1992-1-1 0:0:0.0, None), (1993-1-1
        0:0:0.0, None), (1994-1-1 0:0:0.0, None), (1995-1-1 0:0:0.0, None),
        (1996-1-1 0:0:0.0, None), (1997-1-1 0:0:0.0, None), (1998-1-1 0:0:0.0,
        None)]
List of levels found: [(None, None)]
Scanning /pcmdi/obs/6h/hfls/rnl_ncep/hfls.rnl_ncep.1978.ctl
Scanning /pcmdi/obs/6h/hfls/rnl_ncep/hfls.rnl_ncep.1979.ctl
Scanning /pcmdi/obs/6h/hfls/rnl_ncep/hfls.rnl_ncep.1980.ctl
```

```
...
Scanning /pcmdi/obs/6h/hfss/rnl_ncep/hfss.rnl_ncep.1998.ctl
Scanning /pcmdi/obs/6h/pr/rnl_ncep/pr.rnl_ncep.1978.ctl
...
Scanning /pcmdi/obs/6h/pr/rnl_ncep/pr.rnl_ncep.1998.ctl
Scanning /pcmdi/obs/6h/rlds/rnl_ncep/rlds.rnl_ncep.1978.ctl
...
File not found, was skipped: /pcmdi/obs/6h/rlus/rnl_ncep/rlus.rnl_ncep.1984.ctl
...
Scanning /pcmdi/obs/6h/uvas/rnl_ncep/uvas.rnl_ncep.1998.ctl
sample.xml written
```

cdimport looks first for files which match the directory and template provided. It then lists the variables found in the filenames, the timepoints found in the filenames (as pairs of start and end times), and the levels found in the filenames (as pairs of start and end levels). In this example, the data is not partitioned across vertical levels, so none are listed. There may be a vertical dimension in the files, but data is not split into files across that dimension. If the %v specifier is not used, no variables will be listed either.

In the next phase of the import the matching files are scanned for metadata information. The algorithm for this is straightforward:

```
for each variable appearing in a filename
- for each (first time, last time) in a filename
  - for each (first level, last level) in a filename
    - generate the filename for variable,time,level using the directory and
        template
    - scan the file for metadata
    - merge in the file metadata
```

In the above example, the variable ‘rlus’ does not have data for the year 1984. Since the -g option was specified, the time dimension is treated as linear and gaps are permitted, so this is not considered an error.

The last phase is to write out the accumulated metadata in CDML format. In the above example, this generates the file **`sample.xml`**.

In the above example, the ‘-g’ option specifies that missing times are allowed. If the ‘-s’ option is used instead, the following results:

```
% cdimport -s -v -x junk.xml /pcmdi/obs/6h/ %v/rnl_ncep/%v.rnl_ncep.%Y.ctl
        ncep_reanalysis_6h
...
Scanning /pcmdi/obs/6h/hfls/rnl_ncep/hfls.rnl_ncep.1978.ctl
...
Scanning /pcmdi/obs/6h/psl/rnl_ncep/psl.rnl_ncep.1985.ctl
Scanning /pcmdi/obs/6h/psl/rnl_ncep/psl.rnl_ncep.1986.ctl
```

```
Traceback (innermost last):
  File "/usr/local/bin/cdimport", line 553, in ?
    main(sys.argv)
  File "/usr/local/bin/cdimport", line 169, in main
    dset2 =
         extend(dset2,dset3,extendedTime,timeIsRelative,linearDimList,allowGaps
         ,'T')
  File "/usr/local/bin/cdimport", line 505, in extend
    raise CannotExtend, 'Axis %s is not linear or has the wrong length in the
         PREVIOUS file'%extendDim
Cannot extend a dataset: : Axis time is not linear or has the wrong length in
         the PREVIOUS file
```

The 'previous' file is a reference to data for 1985. Subsequent examination of this file reveals that the last timepoint in that file is missing.

A common error is to misspell the directory or template. In this case, the result will be the message 'No data found'. For example

```
% cdimport -s -v -x junk.xml /pcmdi/obs/6h/ %v/none/%v.rnl_ncep.%Y.ctl
         ncep_reanalysis_6h
...
List of variables found (in filenames): []
List of timepoints found: []
List of levels found: []
No data found
```

6.1.6 Name Aliasing

A problem can occur if variables in different files are defined on different grids. What if the axis names are the same? CDMS requires that within a dataset, axis and variable IDs (names) be unique. What should the longitude axes be named in CDMS to ensure uniqueness? The answer is to allow CDMS IDs to differ from file names.

If a variable or axis has a CDMS ID which differs from its name in the file, it is said to have an *alias*. The actual name of the object in the file is stored in the attribute **name_in_file**. **cdimport** uses this mechanism to resolve name conflicts; a new axis ID is generated, and the **name_in_file** is set to the axis name in the file.

Name aliases also can be used to enforce naming standards. For data received from an outside organization, variable names may not be recognized by existing applications. Often it is simpler and safer to add an alias to the metafile rather than rewrite the data.

6.1.7 Generating Metadata for a File

A single file can be accessed directly in CDMS, without ingesting. However, frequently it is useful to generate an ASCII description of the metadata in the file. To do this, use the filename as the template argument:

```
cdimport . clt.nc sample
```

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